Mapping the visible settings of Designated Landscapes in Wales

Report No: 522
Author Name: Dr Crona Hodges, Henry Batten, Osian Roberts, Dave Dowding

Author Affiliation: Geo Smart Decisions Ltd.

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Mae'r gwaith arloesol hwn yn darparu tystiolaeth ar raddau a phatrymau gwelededd gan edrych i mewn ac oddi allan o Dirweddau Dynodedig (Parciau Cenedlaethol a'r Ardaloedd o Harddwch Naturiol Eithriadol) drwy Gymru. Mae'r adroddiad technegol hwn yn nodi'r dulliau a ddefnyddwyd ac yn dangos canlyniadau'r tair prif dasg:

(1) **Cyfrifwyd parth gwelededd damcaniaethol (ZTV) o bob safle arsylwi allweddol gan edrych i mewn neu oddi allan o'r Tirweddau Dynodedig hyd at bellter o 35km.** Cyfrifwyd uchder cyn i wrthrych fod yn weladwy (HOBV) ar gyfer pob safle tu allan i'r parth gwelededd damcaniaethol. (Staff CNC a fu yn gyfrifol am enwi y safleoedd arsylwi allweddol ger y Tirweddau Dynodedig).

(2) **Cyfrifwyd ZTV cyffredin drwy ddefnyddio o nifer o olygfannau** a gynhyrchwyd gan gyfrifiadur i gynrychioli gwelededd hyd at 35km o unrhyw le mewn Tirwedd Dynodedig. Cyfrifwyd HOBV cyffredin gan ddilyn yr un dull.

(3) **Cyfrifwyd ZTV cyffredin ar gyfer pob ardal Weledol a Synhwyraidd LANDMAP yng Nghymru.** Gan ddilyn y dull yn (2), mae bob ZTV cyffredin yn dangos hyd at 35km i unrhyw gyfeiriad, gan ddynodi hefyd unrhyw linell weledol sydd tu mewn i'r Tirwedd Dynodedig.

Defnydd bwriedig

Effeithir ar y harddwch naturiol sydd dan warchodaeth statudol mewn Tirweddau Dynodedig gan y lleoliad gweladwy, a all ymestyn y tu hwnt i ffin y dynodiad. Trwy fapio maint y gwelededd hwn, gall cynllunio gofodol strategol, llunio polisïau a dewisiadau safle fod yn fwy gwybodus ar adeg cyn i gynigion datblygu penodol godi.

Bydd y dystiolaeth yn arbennig o berthnasol i lywio'r dewisiadau gofodol yn Dyfodol Cymru 2040 Llywodraeth Cymru yn y Cynllun Cenedlaethol (a gyhoeddwyd yn 2021). Yn nodedig, mae'r Cynllun yn cefnogi datblygiad ynni gwynt ar raddfa fawr (Polisi 17) ond nid "*effaith andwyol annerbyniol ar y tirwedd o amgylch (yn enwedig ar osodiad Parciau Cenedlaethol ac Ardaloedd o Harddwch Naturiol Eithriadol*)". (Polisi 18).

Cyfyngiadau

Gwaith wedi'i seilio ar feddalwedd Systemau Gwybodaeth Ddaearyddol (GIS) yw hwn. Nid yw'r gwaith hwn yn asesu effaith weledol, sy'n cynnwys set ehangach o ffactorau. Er ei fod wedi'i wirio, mae'r gwaith yn gyd-destunol ac ni ddylid ei ddefnyddio yn lle ZTV lleol neu asesiad safle-benodol ar effaith datblygiad dros y tirwedd. Er enghraifft, mae pob safle arsylwi allweddol a gynhyrchwyd fel rhan o dasg 1 yn cynnwys 9 pwynt arsylwr mewn sgwâr 90 m x 90 m.

Defnyddiwyd model cydraniad 30 m 'daear foel' ar gyfer y mapio, gan ei fod yn llinell sylfaen gymharol sefydlog. Ystyriwyd crymedd y Ddaear, ond nid rhwystrau lleol fel llysdyfiant neu adeiladau. Gall amodau atmosfferig a goleuo hefyd newid pa mor weladwy y byddai gwrthrych yn ymddangos. Orherwydd hyn, mae'r canlyniadau yn dangos *graddau damcaniaethol mwyaf posibl* o welededd o fewn 35 km.

Mae'r map canlynol yn dangos HOBV ar gyfer Bryniau Clwyd ac AHNE Dyffryn Dyfrdwy. Mae'r atodiadau yn dangos mwy o enghreifftiau o bob un o'r dair prif dasg wedi i'w gyflawni.

Executive summary

Scope and Outputs

This seminal work for Wales provides evidence on the extent and pattern of visibility to and from Designated Landscapes (National Park and Area of Outstanding Natural Beauty - AONB). This technical report sets out the method and illustrates results from three main tasks:

(1) **A 'zone of theoretical visibility' (ZTV) was calculated to 35km distance from each key view point** looking into or out from a Designated Landscape. The 'height object becomes visible' (HOBV) was calculated for those parts without line of sight visibility. (Designated Landscapes and NRW Staff identified the key view points).
(2) **A 'collective' ZTV was calculated from a large number of computer-generated view points** to represent visibility up to 35km distance from anywhere in a Designated Landscape. The collective HOBV was also calculated.
(3) **A 'collective' ZTV was calculated for every LANDMAP Visual and Sensory area in Wales.** Following the method in (2)**,** they show up to 35km in any direction, also denoting any line of sight visibility falling within a Designated Landscape.

Intended uses

The natural beauty under statutory protection in Designated Landscapes is affected by the visible setting, which may extend beyond the designation boundary. By mapping the extent of this visibility, strategic spatial planning, policy-making and site choices can be more informed at a time before specific development proposals arise.

The evidence will be particularly relevant to informing the spatial choices in Welsh Government's Future Wales: The National Plan 2040 (published in 2021). Notably, the Plan supports large-scale wind energy development (Policy 17) but not "*an unacceptable adverse impact on the surrounding landscape (particularly on the the setting of National Parks and Areas of Outstanding Natural Beauty)*". (Policy 18).

Caveats

This is Geographical Information Systems (GIS) software based work. This work does not assess visual <u>impact,</u> which involves a wider set of factors. Although sense-checked, the work is contextual and should not be used in place of bespoke ZTV or development and site specific landscape and visual impact assessment. For example, each single key view point in generated as part of task 1 comprises 9 observer points in a 150m x 150m square.

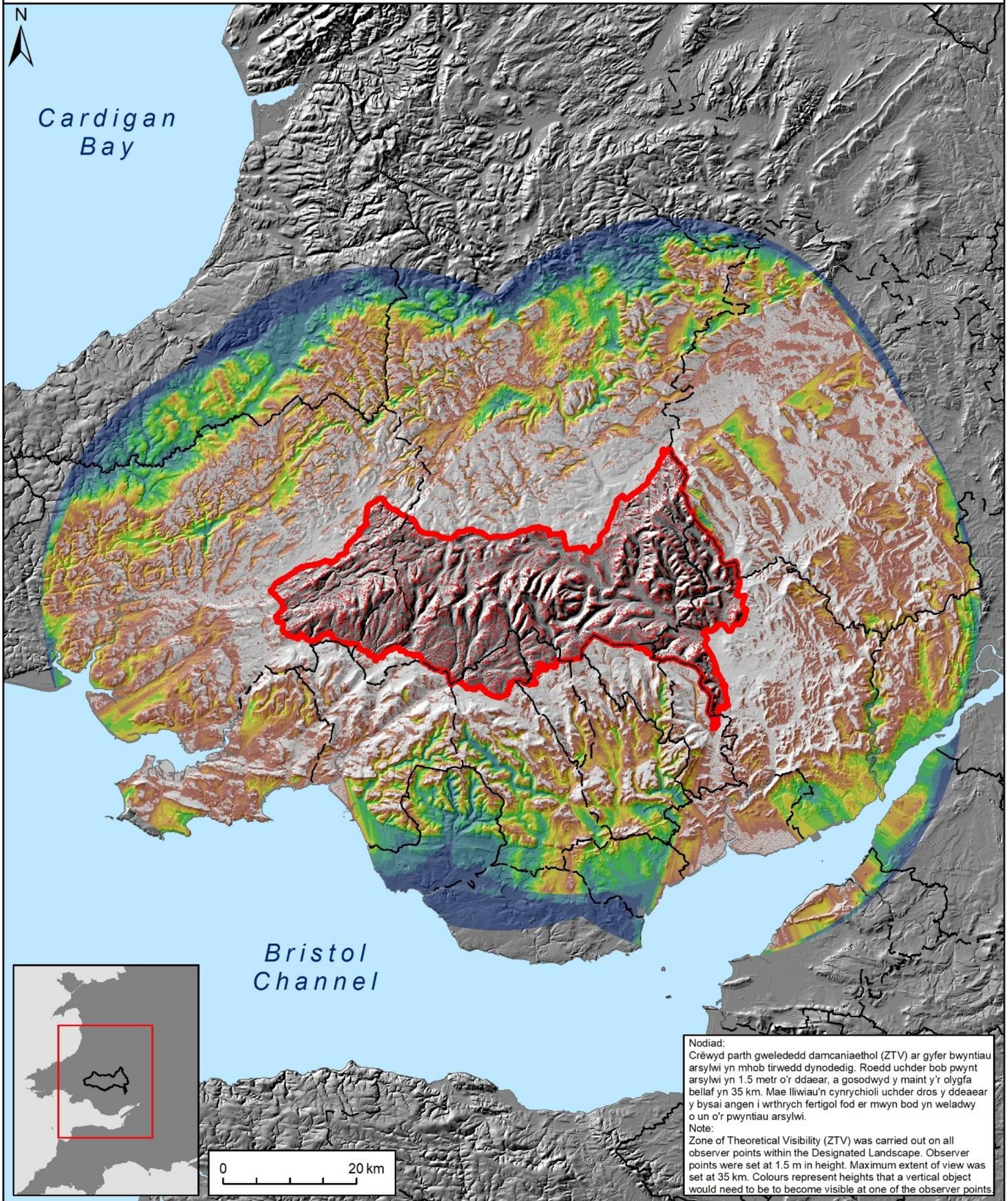
A 30 m resolution 'bare earth' model was used for the mapping, being a relatively stable baseline. The Earth's curvature was into account but not local obstructions such as trees or buildings. Atmospheric and lighting conditions can also alter how noticable an object would appear. As such, the results are the *maximum theoretical extents* of visibility within 35 km.

The map illustrates the HOBV for Clwydian Range and Dee Valley AONB. The appendices illustrate more examples from each of the three main tasks of the work.

Uchder cyn i wrthrych fod yn weladwy | Height Object Becomes Visible (HOBV)

Parc Cenedlaethol Bannau Brycheiniog | Brecon Beacons National Park

Cyfoeth Naturiol Cymru
Natural Resources Wales



Nodiad:
Crëwyd parth gweledEdd damcaniaethol (ZTV) ar gyfer bwyntiau arsylwi yn mhob tirwedd dynodedig. Roedd uchder bob pwynt arsylwi yn 1.5 metr o'r ddaear, a gosodwyd y maint y'r olygfa bellaf yn 35 km. Mae lliwiau'n cynrychioli uchder dros y ddeaear y bysai angen i wrthrych fertigol fod er mwyn bod yn weladwy o un o'r pwyntiau arsylwi.

Note:
Zone of Theoretical Visibility (ZTV) was carried out on all observer points within the Designated Landscape. Observer points were set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent heights that a vertical object would need to be to become visible at one of the observer points.

Allwedd | Legend

- Pwynt arsylwi / Observer point
- Ffin sirol / County boundary
- Ffin Tirwedd Dynodedig / Designated Landscape Boundary
- Gweladwy | Visible

HOBV (m)

- < 25
- 26 - 49
- 50 - 79
- 80 - 108
- 109 - 145
- 146 - 175
- 176 - 225
- 226 - 350
- 350+

Geo Smart Decisions

1. Introduction

Natural Resource Wales (NRW) instructed Geo Smart Decisions to create and present strategic evidence on the visibility of National Parks and Areas of Outstanding Natural Beauty AONB) to their surrounding landscapes in Wales. The key and majority audience for this work will be those considering visual impact isues for strategic planning purposes. The approach applied uses computer GIS software ('Geographical Information Systems') to compute viewsheds or 'Zones of Theoretical Visibility' (ZTVs) in nine Designated Landscapes (DLs) with settings in Wales, these were: Snowdonia National Park, Brecon Beacons National Park, Pembrokeshire Coast National Park, Wye Valley AONB (partly in Wales), Shropshire Hills AONB (wholly in England), Llŷn AONB, Clwydian Range and Dee Valley AONB, Gower AONB and Anglesey AONB. Similar work was previously carried out across England, as documented in a report commissioned by Natural England[1]. The work presented here has built upon the analysis carried out in that report and builds upon the approach taken.

1.1 Calculating ZTVs

The maximum extent of ZTVs was set in the brief at 35 km distance from an observer point. This distance is based on separate research previously commissioned by Natural Resources Wales (NRW) that reviewed distances used in Environmental Impact Assessments over which visual effects were likely to be significant, up to 350 m wind high turbines[2].

ZTV analysis can take on several forms in its calculation. The term 'theoretical' here implies that the calculated viewshed is not truly representative of views on the ground, owing to presence of buildings, trees or other surface features that may obstruct true visibility. It is instead however a mathematical calculation of the surfaces that would intersect with an observer's line of sight. More advanced algorithms consider other features such as the earth curvature and atmospheric effects, however all rely on topography and are thus known as 'Bare Earth Models'.

Bare earth topography is likely to be a more stable and enduring baseline upon which to model the analysis than an elevation model which additionally shows upstanding features such as woodlands and buildings. Although an elevation model could allow a more accurate representation of visibility, it would be subject to continual changes needing updating, such as when a forest plantation is clear-felled or when a new housing estate is built.

When calculating ZTVs, there are multiple model outputs that can be produced. Firstly, ZTV calculation can provide a binary (visible or non-visible) product delineating regions theoretically visible for a human observer located at specific vantage points. Secondly, for regions that are not directly visible to the human observer, certain models can provide

[1] Murdock et al., 2013, GIS Viewshed Analysis to Identify Zones of Potential Visual Impact on Protected Landscapes: A Natural England project. Available at http://www.geodata.soton.ac.uk/geodata/viewshed/

[2] White, S. Michaels, S. King, H. 2019. Seascape and visual sensitivity to offshore wind farms in Wales: Strategic assessment and guidance. Stage 1- Ready reckoner of visual effects related to turbine size. NRW Evidence Series. Report No: 315, 94pp, NRW, Bangor. Available at: https://cdn.cyfoethnaturiol.cymru/media/689503/eng-evidence-report-315-seascape-and-visual-sensitivity-to-offshore-wind-farms-in-wales.pdf

estimates of the height (above ground level) required for an object to *become* visible, henceforth known as 'HOBV' – height object becomes visible.

ZTV analysis can either be carried out on a single observer point, or the combination of many. When undertaking the latter analysis, the binary viewsheds become cumulative viewsheds, combining the visible areas from all observer points. The cumulative viewshed can subsequently be converted into a frequency occurrence layer, or heatmap, showing regions visible from multiple observer points located throughout the landscape.

1.2 Breakdown of Tasks

In consultation with NRW, GSD, identified three main tasks associated with the requirements of this work; these are presented below.

1.3 Task 1: Key Viewpoint Analyses

This first task considered, in consultation with NRW, key viewpoints within each of the nine DLs. The task was split into two output areas, viewsheds and HOBVs. The first resulted in the production of viewsheds at these popular vantage points including both the binary viewshed demarcating the ZTV and a frequency occurrence layer, or 'heatmap', showing regions visible from multiple observer points placed in the immediate vicinity of each key viewpoint. The second output area for this task, HOBV layers, identify the areas that could become visible from each respective viewpoint should a vertical development of a certain height be developed (see Figure 1 below).

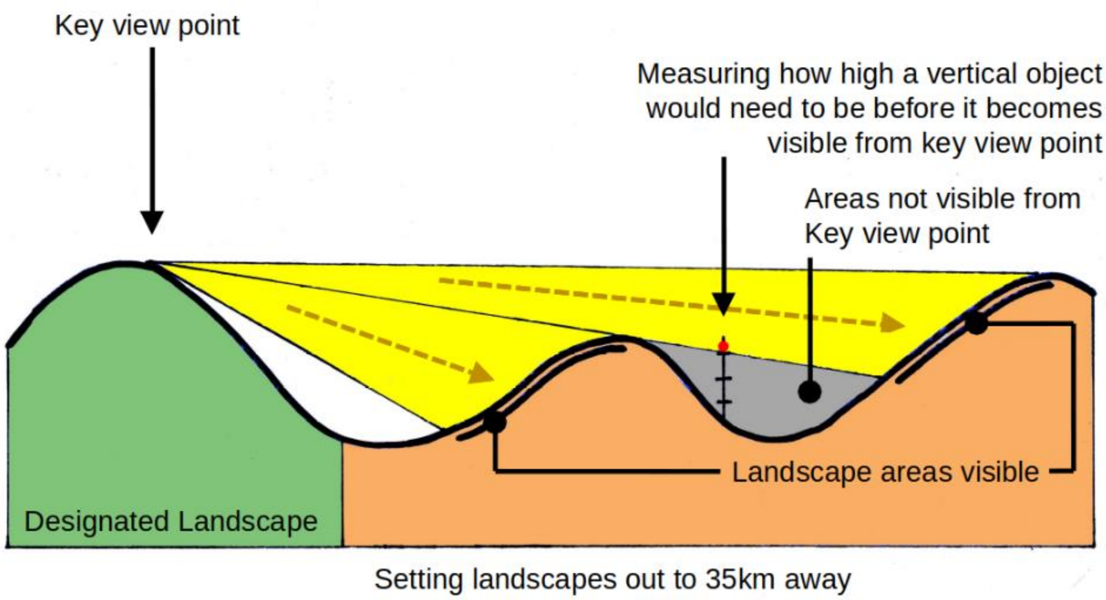


Figure 1. Illustration of Task 1, Key Viewpoints Analyses, ZTV and HOBV creation. *Illustration created and provided by John Briggs, NRW.*

1.4 Task 2: Designated Landscape Analyses

This task focussed on the generation of ZTVs and HOBVs for each of the Designated Landscapes (DLs). Multiple viewpoints were distributed throughout each DL, thus establishing a theoretical viewshed delineating regions visible to individuals standing at positions along relative ridgelines and on summits within each DL (Figure 2). For each DL, GSD generated: (i) a cumulative visibility viewshed demarcating the combined ZTV from all observer locations within the DL, (ii) a heatmap showing regions frequently visible from multiple observer locations, and (iii) a HOBV estimate for regions located outside the cumulative visibility viewshed.

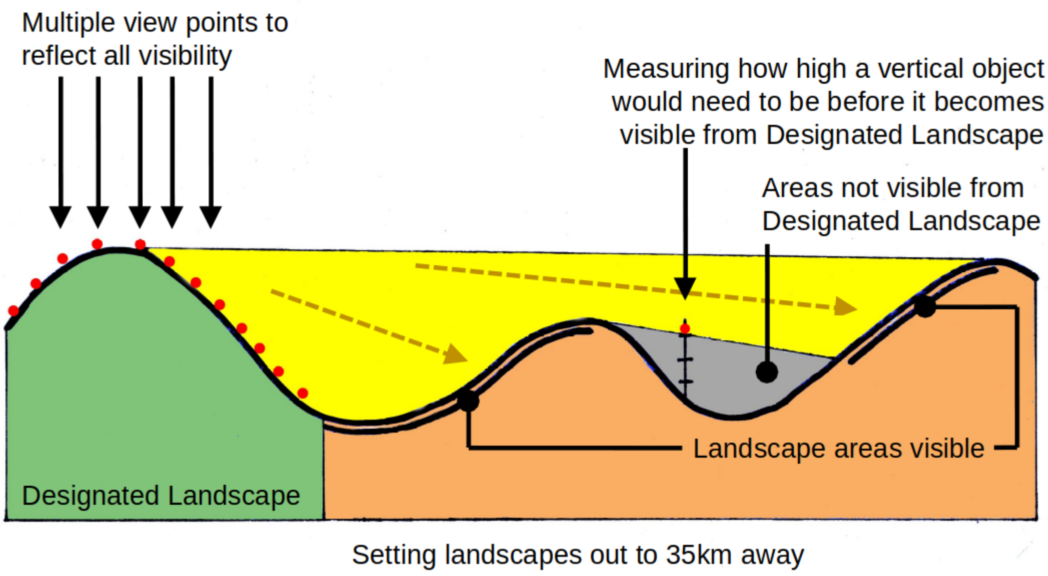


Figure 2. Illustration of Task 2, ZTV and HOBV creation for each Designated Landscape. *Illustration created and provided by John Briggs, NRW.*

1.5 Task 3: Reverse Visibility Analysis

For the third task, GSD calculated ZTVs from small areas outside of the DLs using observer points located along relative ridge lines and summits. The areas used correspond to LANDMAP Visual and Sensory Landscape Areas. These areas are part of the LANDMAP national landscape baseline assessment for Wales. Where the resulting viewshed intersected with a DL, the data was flagged and collated in the final project outputs (see Figure 3 below).

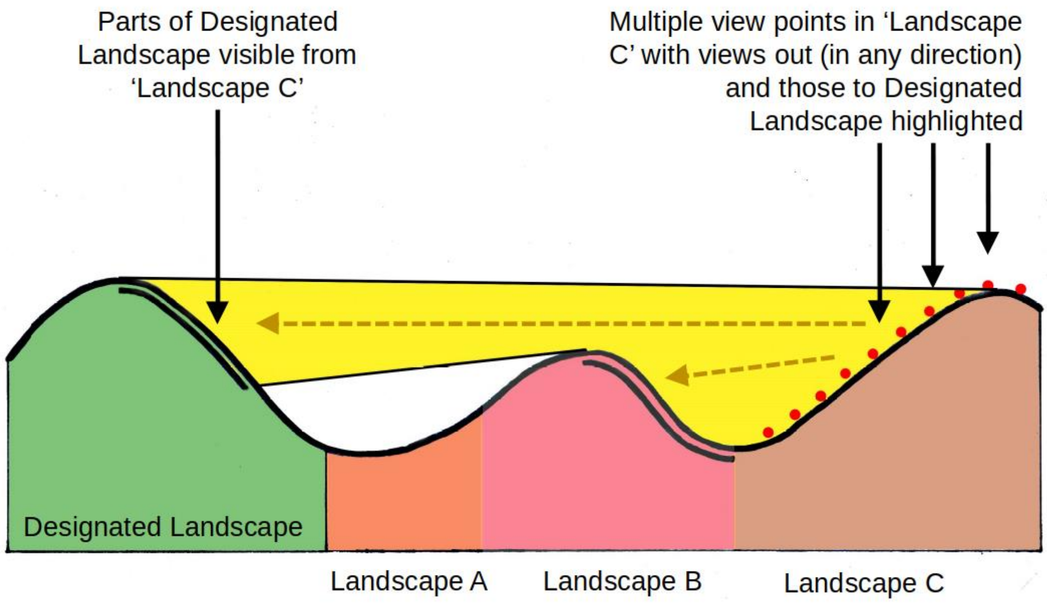


Figure 3. Illustration of Task 3, Reverse Visibility Analysis, ZTVs from Landscape Areas outside of the DL looking in. *Illustration created and provided by John Briggs, NRW*.

2. Methodology

2.1 Development of Observer Points

The creation of observer points and, identifying the most effective and efficient way to do this, was an important component of this work. It was important that obersver points were not too sparse as to yield a false viewshed but were not too dense as to result in over computation, owing to the large memory and storage requirements for combing multiple viewsheds.

The approach taken was to consider topographic peaks and ridges as being most likely to yield the greatest viewshed by area, and so, these features were the focus of the work. A similar study carried out by Natural England (Murdock *et al*. 2013) investigated the volume of necessary observer points, allowing for a brief sensitivity analysis which identified that ± 25% of observer points only yielded a viewshed difference of 1.5%[3].

In order to fully satisfy our questions around the matter of observer point creation, further testing was carried out during the initial phase of this work. This included the use of Landserf[4] software as a way of generating peaks and ridges. As well as Landserf, the use of ESRI ArcGIS software to generate ridgelines was also explored. Whether or not the addition of observer points in the 'planar' regions between ridges was another factor that was considered during this initial phase.

[3] Murdock *et al*., (2013). GIS Viewshed Analysis to Identify Zones of Potential Visual Impact on Protected Landscapes: A Natural England project. Available at http://www.geodata.soton.ac.uk/geodata/viewshed/
[4] Wood, J., (2009). Geomorphometry in landserf. *Developments in soil science*, *33*, pp.333-349.

2.1.1 Peaks and ridgelines

The Landserf package classifies Digital Elevation Models (DEMs) into six unique land features, based upon windowed fuzzy classification of surface parameters such as slope, aspect and height. Of these six classes; *pits, channels, passes, ridges, peaks, and planar surfaces*, peaks were extracted and utilised as observer points.

Upon examination, the ridgelines identified by Landserf were of multiple cell widths, with the resulting ‘ridgeline’ itself being the interpolation of vectorised cell centroids. This created significant false ridgelines that were found to misrepresent the DEM from which they were derived. As a result, alternative ridgeline identification was explored using the ESRI ArcGIS hydrological toolset.

Within ArcGIS, the DEM is firstly inverted, flow direction and flow accumulation layers are there produced[5]. Adjusting the number of cells that create the resultant ‘streams’ yielded features that represented ridgelines that were deemed more topographically truer than the Landserf method. GSD also considered a variation of accumulation thresholds, each of which produced varying densities of ridgelines on the landscape (see Figure 4 below).

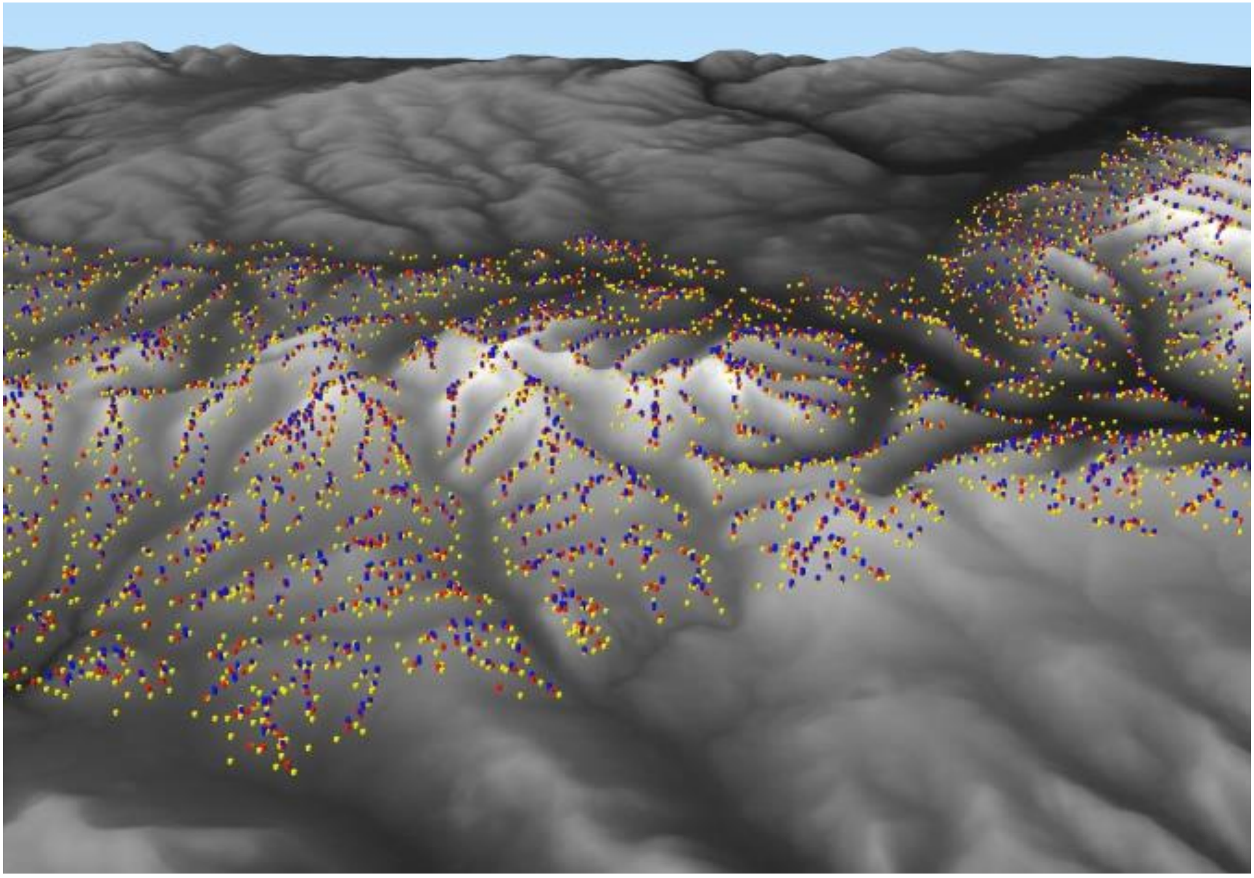


Figure 4. Visual 3D representation of ridgeline variation when different thresholds are applied in the generation, with points extracted at 500m intervals. *Top:* Brecon Beacons, looking Northwards where threshold (T)=50, Yellow, n Points=8304. T=100, Red, n Points= 4403. T=150, Blue, n Points = 3147. Note Elevation is exaggerated by 2x.

[5] https://support.esri.com/en/technical-article/000011289

2.1.3 Additional Points

In the development of the methodology, additional observer points were also generated, based on comments raised in both the Natural England report and when in consultation with NRW. These highlighted the possibility that simply the topographic ridges and peaks of each DL would not be sufficient in highlighting the full theoretical viewshed, especially where ridges were harder to define over gentler slopes, such as on Gower or Anglesey. To test this, points were generated at 100m, 250m and 500m intervals along the ridgelines; a sensitivity analysis was carried out using these different points. As well as this, boundary points were created at 500m intervals along each DL boundary and included in the analysis.

2.1.4 Sensitivity analysis – observer points

Table 1 documents the processing times and modelled viewshed extents for the various combination of observer point generation methods tested. Modelled viewshed extents were found to be highly stable regardless of ridge point spacing or the addition of observer points across planar surfaces and boundaries. The largest difference in viewshed extent was ± 0.76%; a result deemed to be within acceptable error margins by NRW.

2.1.5 LANDMAP Landscape areas

Please see Appendix 9 for details on advanced work with LANDMAP's Visual and Sensory areas (LAs). The report presented in Appendix 9 details how additional Observer Points (OPs) were generated from both *within* the LAs (using methodology outline above *plus* a grid approach) as well as the generation of additional OPs along the boundary lines of each LA. The method of OP generation was altered after initial reviews with NRW of the resultant viewsheds generated to ensure that LAs of a certain shape and area (notably narrow, flat or valley bottom areas with few ridge points) had a sufficient number of associated OPs to ensure that a representative viewshed was created.

Table 1. A comparison of modelled viewshed extents in Snowdonia generated from different observer point generation techniques.

Ridge generation method	Distance between points	Additional points	No. of ridge points (Peak Points)	No. Of Planar Points	Total Points	Processing Time (s)	Change in Area (%)
Landserf	100	None	34685 (495)	0	35180	5604	-0.29
Arc T = 50	100	None	29199 (495)	0	29694	4583	Max Area
Arc T = 75	100	None	20020 (495)	0	20515	2073	-0.24
Arc T = 100	100	None	17388 (495)	0	17883	1752	-0.27
Arc T = 100	250	None	8505 (495)	0	9000	1431	-0.6
Arc T = 100	500	None	5777 (495)	0	6272	991	-0.76
Arc T = 100	50	None	32510 (495)	0	33005	3245	-0.09
Arc T = 100	500	250m Grid on Planar	5777 (495)	15141	21413	3363	-0.55
Arc T = 100	500	500m Grid on Planar	5777 (495)	3785	10057	1582	-0.67
Arc T = 100	500	1000m Grid on Planar	5777 (495)	1483	7755	751	-0.45
Arc T = 100	500	Boundary points	5777 (495)	1445	7717	754	-0.4

The modelled viewsheds were found to be highly consistent when the number of observer points was modified (Table 2). In most designated landscapes, the variation in viewshed extent was ± 1%, however the magnitude of variance was higher in the Wye Valley, where a change of ± 3.6% was recorded as the number of observer locations was reduced from 1872 to 607. In general, we found that several hundred well-positioned observer points was sufficient to provide reliable and consistent viewsheds. The addition of further viewpoints only served to increase processing times with negligible variation in viewshed extent.

Table 2. Viewshed extents modelled with varying numbers of observer points.

Designated Landscape	Observation Points	Processing Time (s)	Viewshed Area (ha)	Change in Area (%)
Anglesey	1075	30	636800	-
Anglesey	481	30	630385	-1.01
Anglesey	319	30	627917	-1.39
Brecon Beacons	8304	810	522868	-
Brecon Beacons	4403	462	517888	-0.95
Brecon Beacons	3147	332	517299	-1.07
Clwydian	4794	463	491139	-
Clwydian	2539	250	488912	-0.45
Clwydian	1411	138	486571	-0.93
Gower	9251	915	382559	-
Gower	1045	106	377737	-1.26
Gower	474	48	373834	-2.28
Llŷn	1061	105	610767	-
Llŷn	520	54	608612	-0.35
Llŷn	321	33	604735	-0.99
Pembrokeshire	7453	704	964570	-
Pembrokeshire	5418	519	962187	-0.25
Pembrokeshire	4269	406	960113	-0.46
Shropshire Hills	9259	923	479055	-
Shropshire Hills	5069	510	477056	-0.42
Shropshire Hills	2903	273	474074	-1.04
Wye Valley	1872	178	275585	-
Wye Valley	1070	106	268934	-2.41
Wye Valley	607	60	265792	-3.55

2.2 Sources of elevation data

During the initial testing phase of the work, several sources of elevation data ('digital terrain models' – DTMs) were evaluated for the estimation of ZTV outputs and genersted HOBV layers. The following datasets were considered as part of this analysis:

a. 50 metre DTM (herein referred to as "OS Terrain 50") acquired through aerial photogrammetry (Ordnance Survey, 2020)[6],
b. 30 metre DTM (herein referred to as "SRTM") obtained from spaceborne radar interferometry (Van Zyl, 2001)[7], and
c. 10 metre DTM (herein referred to as "NextMap") collected using aerial radar interferometry (Intermap Technologies, 2007)[8].

Due to time constraints, we limited our testing to the Llŷn AONB landscape. Our experiments were conducted using the QGIS processing algorithm[9] with 1061 observer points.

2.2.1 Extents of ZTVs

The model outputs revealed that different sources of elevation data had a moderate impact on the viewshed extents (Table 3). When using the OS Terrain 50 m DTM, the viewshed area increased by 4.7% when compared against the results obtained with the NextMap 10 m DTM. Conversely, the SRTM (30 m) DTM produced a viewshed that was highly consistent with the results obtained from the NextMap product (± 0.95%). Additional experiments were subsequently conducted to determine how these variations were influenced specifically by the spatial resolution of the elevation data.

Table 3. Viewshed extents modelled using different sources of elevation data over the Llŷn AONB.

DTM Source	Spatial Resolution (m)	Viewshed Area (ha)	Change in Area (%)
NextMap	10	113327	-
SRTM	30	112252	-0.95
OS Terrain 50	50	118615	4.67

Note: Viewshed extent over land (following the removal of aquatic regions)

[6] Ordnance Survey (2020). OS Terrain 50. Available: www.ordnancesurvey.co.uk/opendata. Accessed: March, 2021.
[7] Van Zyl, J. J. (2001). The Shuttle Radar Topography Mission (SRTM): a breakthrough in remote sensing of topography. *Acta Astronautica*, *48*(5-12), 559-565.
[8] Intermap Technologies (2007). NEXTMap British Digital Terrain Model Dataset Produced by Intermap. NERC Earth Observation Data Centre. Available: http://catalogue.ceda.ac.uk/uuid/8f6e1598372c058f07b0aeac2442366d. Accessed: March, 2021
[9] Cuckovic, Z. (2016). Advanced viewshed analysis: A Quantum GIS plug-in for the analysis of visual landscapes. *Journal of Open Source Software*, 1(4), 32. doi:10.21105/joss.00032

2.2.2 HOBVs and DTM sources

The HOBV values derived from different DTM sources were consistent, with a median difference of 2.97 and 3.43 metres between the results obtained with the high-resolution NextMap DTM and the SRTM and OS Terrain 50 datasets (Table 4). However, the OS Terrain 50 DTM was unreliable for the estimation of HOBV in some locations due to large errors (Figure 5). Unfortunately, we were unable to determine if these errors were associated with (a) limitations of the remote sensing techniques used to derive ground elevation, or (b) the spatial resolution of the data. It is plausible that the photogrammetrically derived OS Terrain 50 dataset contains erroneous ground elevations in locations where the ground has been occluded by dense vegetation (Gil *et al.*, 2013; Rogers *et al*., 2020)[10]. In any case, the HOBV errors associated with the SRTM elevation data were several magnitudes smaller, indicating that this dataset could potentially be used to calculate HOBV in an accurate and computationally efficient manner.

Table 4. A comparison of HOBV values modelled using different sources of elevation data over the Llŷn AONB landscape.

DTM Source	Spatial Resolution (m)	Mean HOBV (m)	Mean Absolute Error (m)	Median Absolute Error (m)
NextMap	10	243.3 ± 341.5	-	-
SRTM	30	241.0 ± 339.0	5.8 ± 7.8	2.97
OS Terra 50	50	239.5 ± 337.0	7.2 ± 15.7	3.43

Note: Statistics derived from HOBV values at > 3000 validation points located over land.

[10] Gil, A. L., Núñez-Casillas, L., Isenburg, M., et al. (2013). A comparison between LiDAR and photogrammetry digital terrain models in a forest area on Tenerife Island. *Canadian Journal of Remote Sensing*, *39*(5), 396-409.
Rogers, S. R., Manning, I., & Livingstone, W. (2020). Comparing the spatial accuracy of Digital Surface Models from four unoccupied aerial systems: Photogrammetry versus LiDAR. *Remote Sensing*, *12*(17), 2806.

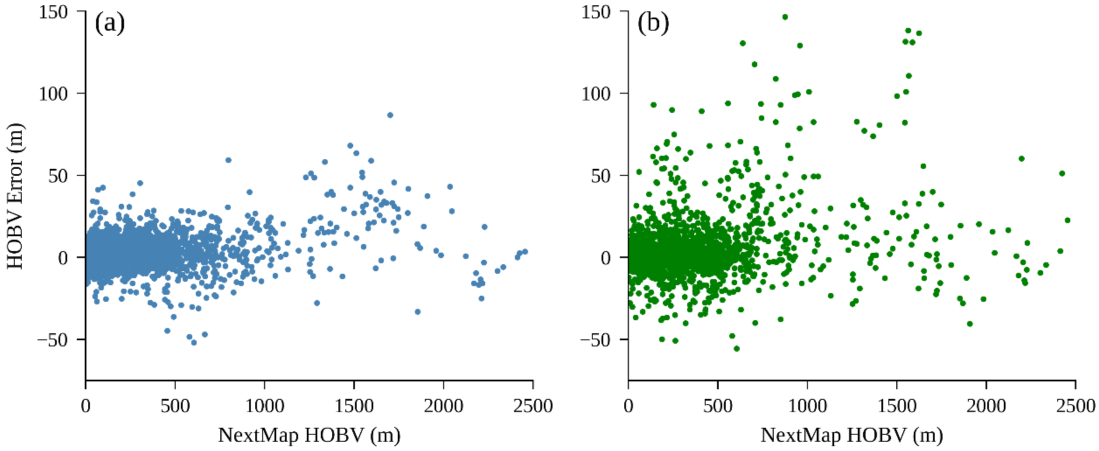


Figure 5. Scatter diagrams showing the distribution of errors in predicted HOBV values over the Llŷn designated landscape with SRTM (a) and OS Terrain 50 (b) elevation data when compared against the NextMap 10 m resolution DTM.

2.2.3 Further exploration of DTM resolution

To investigate the impact of varying DTM spatial resolutions on model outputs, the NextMap 10 metre DTM was downsampled (using cubic interpolation) to spatial resolutions of 20, 30, 40 and 50 metres. ZTV extents and HOBV layers were then generated from observer points within the Llŷn AONB landscape for each of the DTM resolutions.

To evaluate the variance between model outputs, more than 6000 validation points were generated; these were distributed throughout the landscape, with a minimum separation of 50 metres between each point to ensure that each pixel was only sampled once. For each validation point, the absolute difference was calculated between the predicted HOBV values and the baseline HOBV values obtained from the highest resolution 10-metre DTM. Subsequently, covariance was investigated between errors in the HOBV values and other geographic factors such as slope gradient, aspect and Euclidean distance to the observer locations.

The modelled viewshed extents were found to be highly stable irrespective of the spatial resolution of the elevation data (Table 5). At a spatial resolution of 30 m, variability in the total ZTV extent was less than 0.66%, indicating that the use of a 30 m DTM was sufficient to produce reliable and consistent viewsheds for the Llŷn AONB.

Table 5. Viewshed extents modelled using elevation data of varying spatial resolution over the Llŷn AONB landscape.

DTM Resolution (m)	Viewshed Area (ha)	Change in Area (%)
10	106986	-
20	107312	0.30
30	107693	0.66
40	104796	-2.09
50	105019	-1.87

Note: Viewshed extent over land (following the removal of aquatic regions).

The results from this testing also revealed that low spatial resolution DTMs produced HOBV values that differed significantly from those calculated at 10 metre resolution (Table 6). Variability in the HOBV values decreased progressively as the spatial resolution of the DTM was increased. At 30 m pixel resolution, the median absolute error (MAE) was just 0.75 m, decreasing to 0.5 m at 20 m resolution. Figure 6 illustrates that the HOBV errors were positively skewed (Skewness = 0.6-1.6), indicating a tendency for HOBV to be overestimated rather than underestimated as the spatial resolution of the DTM was lowered. Further analysis of the error probability distributions (Figure 7) revealed that 50-60% of errors were less than 1 m, 74-83% were below 5 m, and 83-93% were less than 10 m across all spatial resolutions.

Although coarser DTMs were generally associated with higher uncertainties, it was observed that variations in HOBV were weakly correlated with geographic factors such as slope gradient, slope aspect or Euclidean distance to the observer locations (Table 7). These findings demonstrated that there was no systematic error in the HOBV calculation due to geographic factors.

Table 6**.** Errors in modelled HOBV values from DTMs of varying spatial resolution over the Llŷn AONB landscape.

DTM Resolution (m)	Mean Absolute Error (m)	Median Absolute Error (m)
20	5.0 ± 4.4	0.5
30	7.4 ± 6.9	0.75
40	10.1 ± 8.6	0.97
50	10.8 ± 10.1	1.35

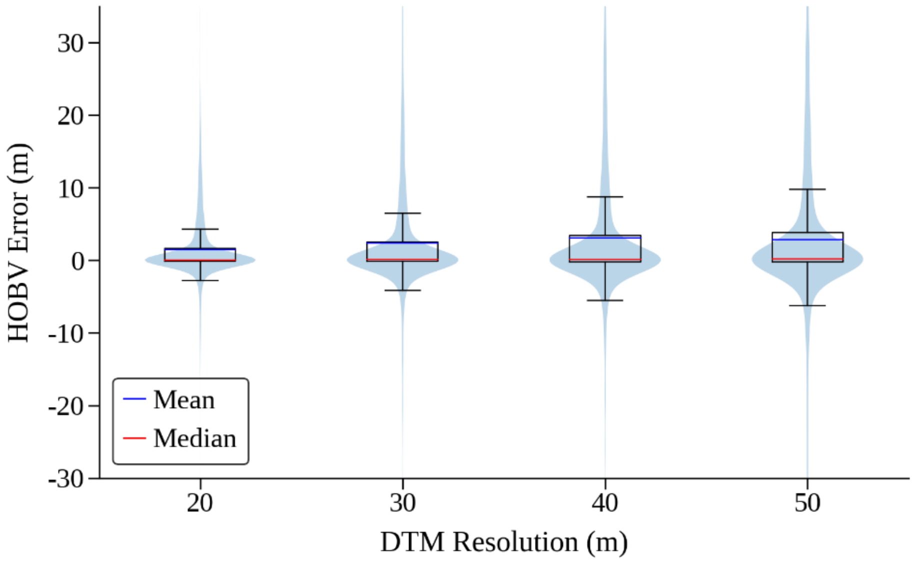


Figure 6. A violin plot illustrating the distribution of errors in modelled HOBV values when using digital terrain models of varying spatial resolution.

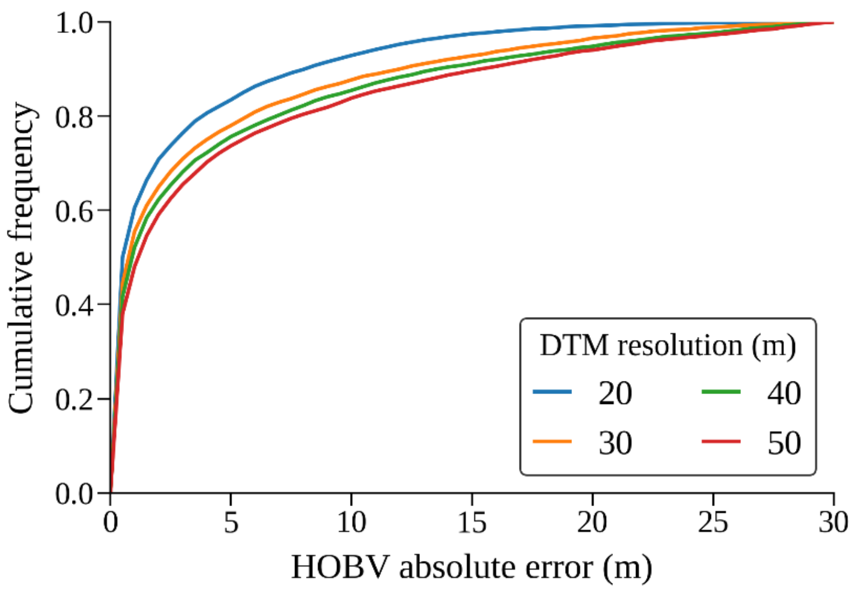


Figure 7. Cumulative distribution functions for HOBV errors recorded with digital terrain models of varying spatial resolution.

Table 7. A Pearson correlation matrix showing weak linear relationships between geographic factors and errors in HOBV at varying DTM spatial resolutions.

Geographic Variable	HOBV Error 20m	HOBV Error 30m	HOBV Error 40m	HOBV Error 50m
Slope aspect	-0.03	0.00	0.29	0.06
Slope gradient	0.18	-0.02	0.00	0.08
Euclidean distance to observer	0.15	0.18	-0.02	0.02

2.3 Choice of algorithm

Previous research has demonstrated that the greatest source of uncertainty in ZTV or viewshed analysis is the choice of algorithm used to compute the viewshed (Fisher, 1993; Kim *et al*., 2004; Nutsford *et al*., 2015)[11]. In light of these findings, we tested two open-source algorithms for viewshed analysis:

- A Quantum GIS (QGIS) plugin developed by Cuckovic (2016)[12], and
- An algorithm in the Geospatial Data Abstraction Library (GDAL) following the methodology developed by Wang et al. (2000)[13].

To compare outputs from these two algorithms, viewshed analysis was carried out on observer points located in the Llŷn AONB landscape with the same elevation data (30 m DTM from SRTM). The Earth curvature coefficient was set to 0.85714, and the atmospheric refraction coefficient to 0.143, on both models, to ensure that the results from the two were directly comparable.

Our experiments revealed that the choice of algorithm did indeed exert a significant impact on the total viewshed extent. The QGIS plugin generated a viewshed that was 10.7% larger than that produced by the GDAL algorithm. These large discrepancies were several magnitudes greater than the variation encountered due to changes in the DTM resolution and/or the number and positioning of observer points.

The choice of algorithm also exerted a significant impact on the modelled HOBV values. Across the Llŷn AONB landscape, the mean difference in modelled HOBV was 13.4 ± 18.6 metres (Median = 4.75 m). These findings were largely in agreement with published literature, demonstrating that the choice of algorithm exerted a dominant influence on the

[11] Fisher, P. F. (1993). Algorithm and implementation uncertainty in viewshed analysis. *International Journal of Geographical Information Science*, *7*(4), 331-347.
Kim, Y. H., Rana, S., & Wise, S. (2004). Exploring multiple viewshed analysis using terrain features and optimisation techniques. *Computers & Geosciences*, *30*(9-10), 1019-1032.
Nutsford, D., Reitsma, F., Pearson, A. L., & Kingham, S. (2015). Personalising the viewshed: Visibility analysis from the human perspective. *Applied Geography*, *62*, 1-7.
[12] Cuckovic, Z. (2016). Advanced viewshed analysis: A Quantum GIS plug-in for the analysis of visual landscapes. *Journal of Open Source Software*, 1(4), 32. doi:10.21105/joss.00032
[13] Wang, J., Robinson, G. J., & White, K. (2000). Generating viewsheds without using sightlines. *Photogrammetric engineering and remote sensing*, *66*(1), 87-90

accuracy and precision of products derived through viewshed analysis. As such, the QGIS algorithm was selected and used for processing all of the project outputs.

Table 8. A comparison of viewsheds generated over the Llŷn AONB landscape using different processing algorithms.

Viewshed Algorithm	Viewshed Area (ha)	Change in Area (ha)	Change in Area (%)
GDAL	94382	-	-
QGIS Plugin	104495	10113	10.71

In presenting the map images for HOBV in this report, a colour scale was used. Its calibrations match the wind turbine height categories used in recent NRW Landscape and Visual Impact assessment guidance,[14] allowing direct cross-reference.

2.4 Key Viewpoints

The comments by users of the Natural England product reported suggestions that the viewsheds derived from peaks and ridges may not solely provide the collective visibility that users of the national parks may experience, owing to the unique networks of footpaths and trails in each area. To address this, NRW initially proposed utilising Strava Metro GPS data, however difficulties in acquiring this data for timely use ultimately meant this idea could not be acted upon. As an alternative, key NRW stakeholders identified 200 key viewpoint locations, for each of the DLs, to use in our analyses. Collective visibility and HOBV viewsheds were calculated at these locations.

To address any potential issues of error derived from the exact location of the viewpoint, particularly with respect to DEM resolution and the HOBV calculation, a 'neighbourhood window' of 3x3 (9 pixels) was created around each key viewpoint, this enabled the creation of a heatmap from the viewsheds using the results from the 9 points at the key viewpoint location. Furthermore, a subsequent search was applied to these generated grids to find the highest DEM elevation pixel, within this grid, surrounding the key view. This was then applied in the calculation of the HOBV layer.

2.5 Reverse Visibility

For the reverse visibility calculations, a method of first segmenting the area surrounding each DL had to be identified before the creation of observer locations. In consultation with NRW, the LANDMAP Visual Sensory layer was utilised; this is divided into almost 2000 individual polygons, or 'Landscape Areas'[15]. These Landscape Areas were represented by individual Survey IDs, which allowed a unique processing ID.

[14] Natural Resources Wales. (2021). Using LANDMAP in Landscape and Visual Impact Assessments. Guidance Note GN46. Available on-line at https://naturalresources.wales/guidance-and-advice/business-sectors/planning-and-development/evidence-to-inform-development-planning/using-landmap-in-landscape-and-visual-impact-assessments-gn46/?lang=en

[15] https://lle.gov.wales/catalogue/item/LandmapVisualSensory/?lang=en

To create observer points for the Landscape Areas, peaks and ridgelines were identified for the whole of Wales. This involved utilising Landserf, once again, for the peak identification as well as ArcGIS to calculate the ridgelines. However, whilst the resulting viewshed from different ridgeline thresholds was explored for each of the DLs, the list of Landscape Areas was too exhaustive to test on an individual basis. Because of this, a set threshold of T=50 was used to produce the ridgelines for all Landscape Areas.

Once the observer points of peaks and ridgelines were created, they were then intersected with the LANDMAP Visual Sensory polygons. Not every individual Landscape Area intersected with some observer points, owing to the polygon representing a region, such as a water bodies or valley floor, with no generated observer points. In total, 101 polygons were omitted through this intersection, leaving 1890 Landscape Areas.

The analysis of reverse visibility presented a significant challenge in terms of combining the 1890 individual viewsheds to form layers that were interpretable and easily presented on the NRW’s open data portal. This was difficult, as views into a DL would overlap, and so visualising this, whilst maintaining a reference to the original Landscape Area, from which the view originated, was too complex for single band images. As a result, a variety of outputs were generated.

Individual Landscape Areas ZTVs were produced, with a classification applied that identified visible areas and inparticular those within individual DLs. These viewsheds were also extracted and categorised for each DL so that NRW could have direct access to all the Landscape Areas with views into each respective DL. Finally, these layers were combined to form Geopackage rasters for each DL. Within these packages, each raster layer was named according to the ID of the Landscape Area, containing information that highlighted the area, as well as the viewshed into the DL. This means users can quickly gather the data for either specific Landscape Areas or interrogate a geospatial layer for all the views into any of the DLs analysed in this study.

2.6 Summary of approach

The results from testing in the initial phase of this work demonstrated that the greatest source of uncertainty in viewshed creation was the choice of processing algorithm. When contrasting two popular and well-established algorithms for viewshed analysis, we recorded a variation of ± 10.7 % in total viewshed extent. This source of variation was significantly greater than that encountered from different sources of elevation data (± 4.7%), from varying DTM spatial resolutions (± 2.1%) or alterations to the numbers and positioning of observer points throughout the landscape (± 3.6%).

Significant correlations between geographic factors (slope gradient, slope aspect and Euclidean distance to observer points) and variations in viewshed extent or HOBV values were not observed. This demonstrated that the model outputs did not contain systematic errors, and that uncertainties were primarily caused by the choice of algorithm and the source of elevation data used to compute the viewsheds.

Following consultation with NRW, the analysis carried out over the DLs across Wales was conducted using: (a) the Quantum GIS plugin developed by Cuckovic (2016)[16], and (b) a 30 m digital terrain model sourced from the Shuttle Radar Topography Mission (Van Zyl, 2001). The QGIS algorithm was chosen based on a visual examination of model outputs by NRW personnel, who on the basis of expert local knowledge, concluded that the QGIS algorithm produced more reliable viewsheds.

The use of a 30 m DTM was justified based on the results from testing in this initial phase of the work as outlined above. This suggests that the SRTM data produced results of comparable accuracy to higher-resolution elevation data. Moreover, this source of elevation data has the added benefit of not being restricted by licensing requirements, thereby allowing derived products to be shared freely on NRW websites and other channels.

3. Results

3.1 Overview of Results

The results of the viewshed analysis have been distributed to NRW in the open-source GeoTiff raster file format (Ritter & Ruth, 1997)[17] to enable widespread dissemination across all mainstream GIS software platforms. To facilitate rapid transferal over the internet, each GeoTiff image has been compressed using the deflate algorithm, and internal overviews have been pre-computed to allow the images to be loaded directly into GIS software. All rasters have been provided at a spatial resolution of 30 m in both the vertical (N-S) and horizonal (E-W) dimensions.

For the analysis of Key Viewpoints and Designated Landscapes, each ZTV has been demarcated using binary rasters, where values of 1 indicate that the pixel is within the observable viewshed (Figures 8 & 11). The cumulative heatmaps, showing regions frequently visible from multiple observer locations, were created in rasters comprised of unsigned integers. These have been provided as both raw counts and as percentages, relative to the number of observer points (Figures 9 & 12). A suitable colour scheme for these heatmaps should reflect a cool to hot transition; representing theoretical 'hot' and 'cold' regions that are visible from a large or small proportion of observer viewpoints. Examples are provided in Appendix 2.

The HOBV rasters contain floating point values denoting the height (in metres above ground level) at which an object becomes visible from observer locations. Following consultations with NRW, the floating-point HOBV values were classified into integers using two classification approaches. In the first approach, the HOBV values were classified at 10 metre vertical intervals up to 350 metres (including an additional class for all regions > 350 m), producing rasters with pixel values ranging from 1-36 (Figure 14). Conversely, in the second approach, the HOBV values have been classified at 10 irregular height intervals designed

[16] Cuckovic, Z. (2016). Advanced viewshed analysis: A Quantum GIS plug-in for the analysis of visual landscapes. *Journal of Open Source Software*, 1(4), 32. doi:10.21105/joss.00032
[17] Ritter, N., & Ruth, M. (1997). The GeoTiff data interchange standard for raster geographic images. *International Journal of Remote Sensing*, *18*(7), 1637-1647.

to replicate common thresholds used in wind turbine planning applications (Table 9 & Figure 15). See Appendix 1 for examples of the HOBV outputs.

Table 9. HOBV classification thresholds for use with wind turbine planning applications.

Class / Pixel Value	HOBV Threshold
1	< 1.5 m
2	1.6 – 25 m
3	26 – 49 m
4	50 – 79 m
5	80 – 108 m
6	109 – 145 m
7	146 – 175 m
8	176 – 225 m
9	226 – 350 m
10	> 351 m

To facilitate widespread use of the data, the GIS layers provided needed to be easily interpretable; an issue consistently raised in the Natural England report due to the adoption of a red-to-green colour scheme for the representation of HOBV (Murdock et al., 2013)[18]. Following consultations with NRW, a multipart colour scheme indicative of varying heights was selected for the visualisation of the HOBV outputs. The following sections illustrate some example outputs for each of the key deliverables – other examples are provided in the Appendices at the end of this document.

3.2 Key Viewpoint Analysis

Three geospatial layers were generated for each of the 200 key viewpoints identified throughout Wales by NRW personnel:

i. a binary viewshed demarcating the Zone of Theoretical Visibility (Figure 8),

ii. a heatmap showing regions visible from 9 observer points placed in the immediate vicinity of each key viewpoint (Figure 9), and

iii. an estimate of the Height Objects Become Visible (HOBV) above ground level for regions located outside the observable viewshed (Figure 10).

Our approach to mapping the ZTV at selected viewpoints differs from prior studies in the use of a 3x3 window of image pixels to create a buffer region around each key viewpoint. We believe that this approach was justified to minimise: (a) GPS positional errors in the viewpoint locations, (b) topographic errors in the digital terrain model, and (c) the placing of key viewpoints behind natural features such as vegetation that would normally occlude the

[18] Murdock et al., (2013). GIS Viewshed Analysis to Identify Zones of Potential Visual Impact on Protected Landscapes: A Natural England project. Available at http://www.geodata.soton.ac.uk/geodata/viewshed/

observable viewshed from the perspective of a human standing on the terrain. The ZTV presented in Figure 8 below therefore represents the maximal viewshed that is theoretically observable from locations in the immediate vicinity of the key viewpoint.

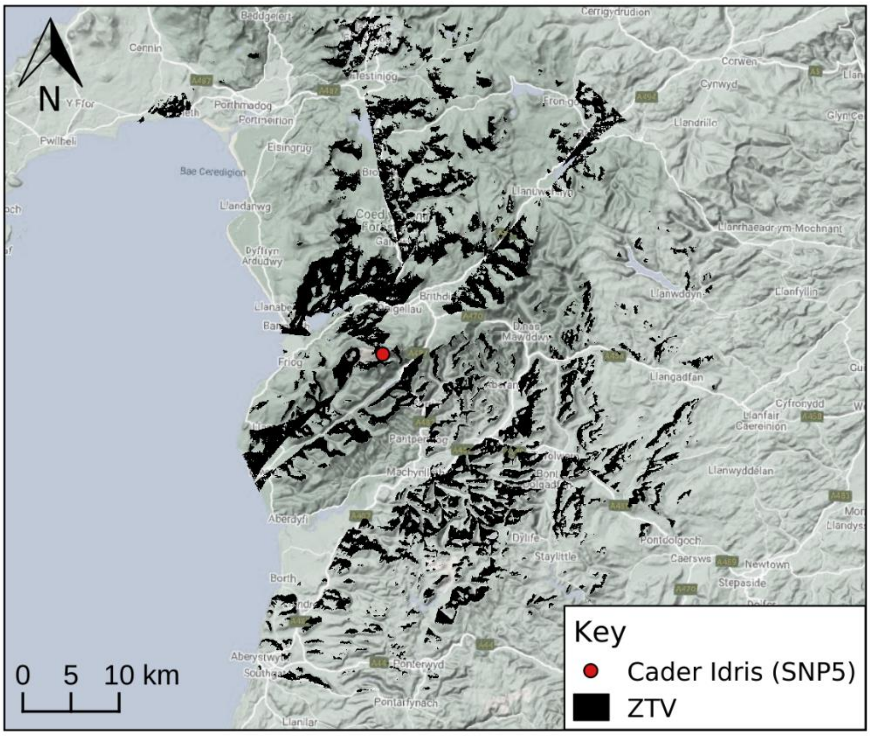


Figure 8. A Zone of Theoretical Visibility (ZTV) from Cader Idris (Key Viewpoint SNP5).

The use of a 3x3 window of image pixels around each key viewpoint also enabled the production of additive heatmaps (Figure 9) illustrating the frequency a pixel was identified as being within the observable viewshed. This layer can also be interpreted as a measure of certainty that a pixel is within the observable viewshed. For instance, pixels observable in all 9 viewsheds have a 100% certainty of being visible from the key viewpoint, whereas pixels observable in only 6 out of 9 viewsheds have a 66% certainty of being visible.

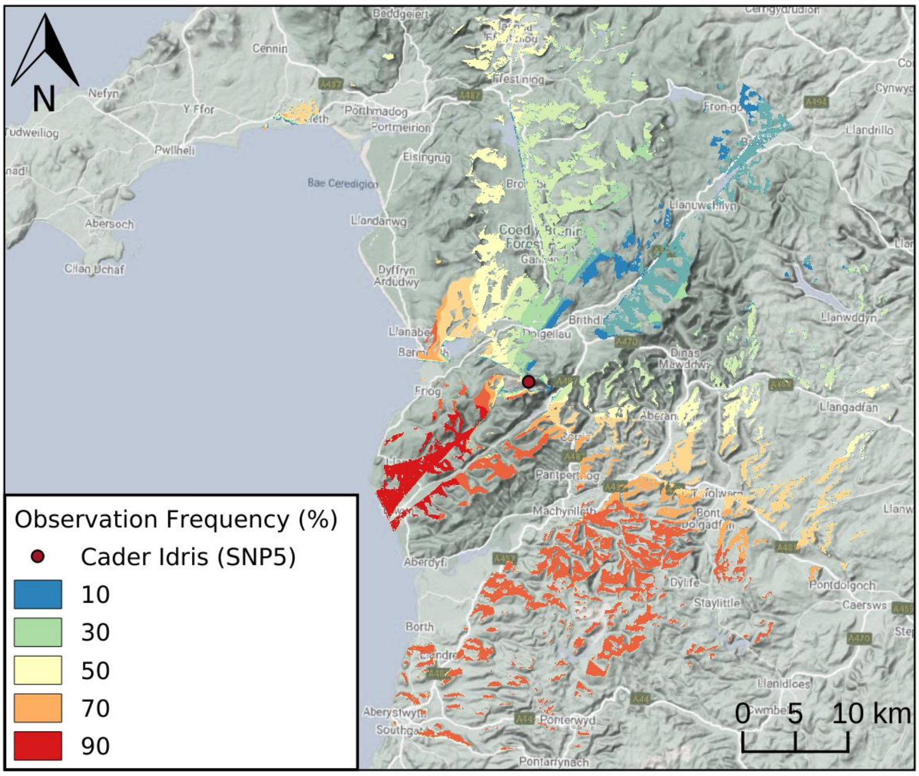


Figure 9. A heatmap showing the frequency that locations are observable from Cader Idris (Key Viewpoint SNP5).

For each key viewpoint, a HOBV layer was also generated (Figure 10). This dataset provides the height (in metres above ground level) that an object would need to be in order to become visible to the human observer standing at the key viewpoint.

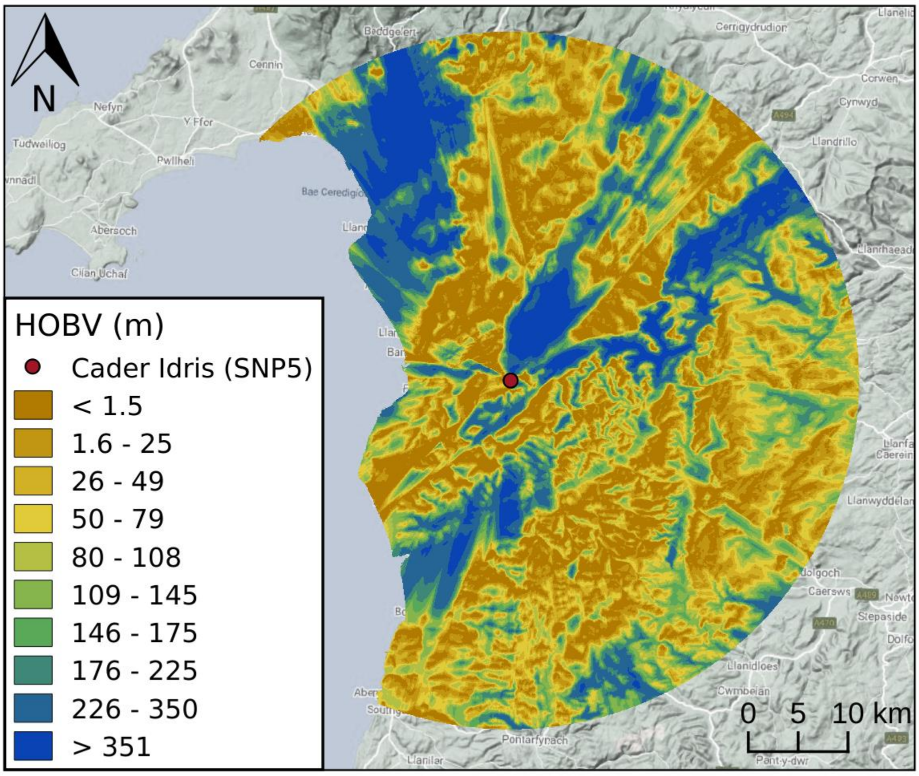


Figure 10. A map of HOBV values from Cader Idris (Key Viewpoint SNP5).

3.3 Designated Landscape Analysis

In each of the 9 DLs, a collective visibility viewshed (Figure 11) was generated by combining the individual ZTV generated from each observer point. These viewsheds represents the maximal zone that is theoretically observable when looking outwards from each DL into the surrounding landscape from observation points situated along prominent peaks and ridges. This dataset therefore allows users to determine whether an object located outside a DL is directly observable from within the protected area.

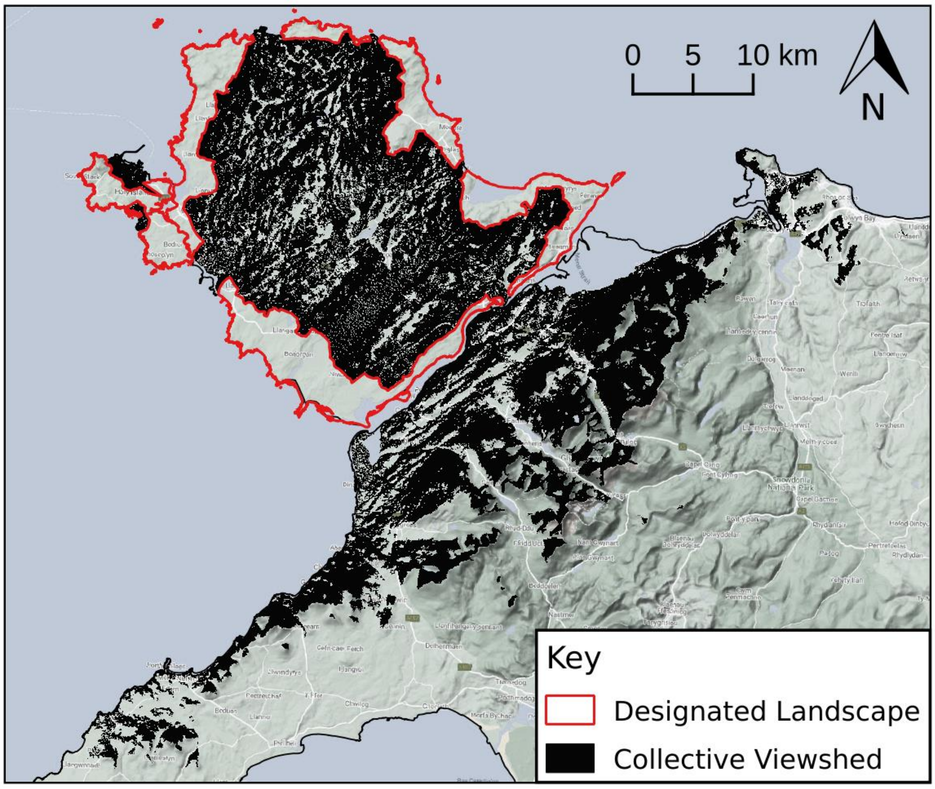


Figure 11. A collective visibility viewshed showing visible regions surrounding the Anglesey AONB.

The collective visibility heatmaps (Figure 12) illustrate the number of times a pixel was identified as being observable from different observer positions within each DL. This dataset therefore quantifies the frequency at which a location is directly visible from multiple observer locations within the DL.

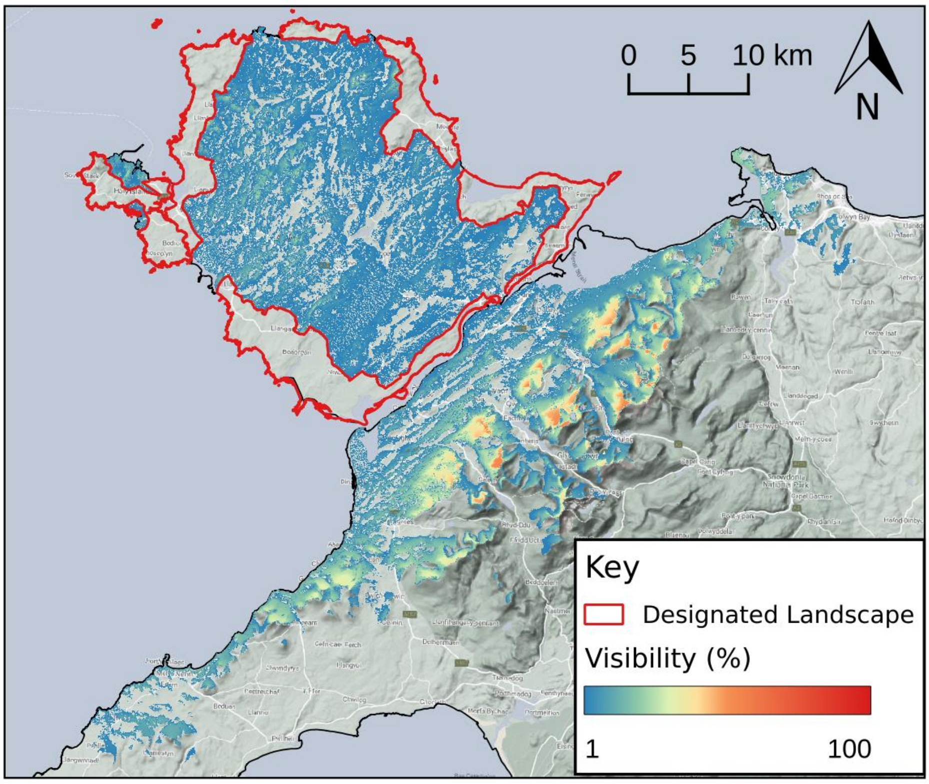


Figure 12. A collective visibility heatmap showing regions frequently visible from different observer positions within the Anglesey AONB.

An estimate of the Height at which Objects Become Visible (HOBV) to a human observer within the DL has been provided for regions falling outside the collective visibility viewshed. As previously noted, the HOBV analysis produced three geospatial datasets:

1. HOBV in metres above ground level,
2. HOBV values classified at 10 metre vertical intervals up to 350 m, and
3. HOBV values classified at irregular height intervals to replicate common thresholds used in wind turbine planning applications (Figure 13).

These datasets provide an estimate of the height (in metres above ground level) that an object would need to be in order to become visible to a human observer standing at prominent positions within the DL.

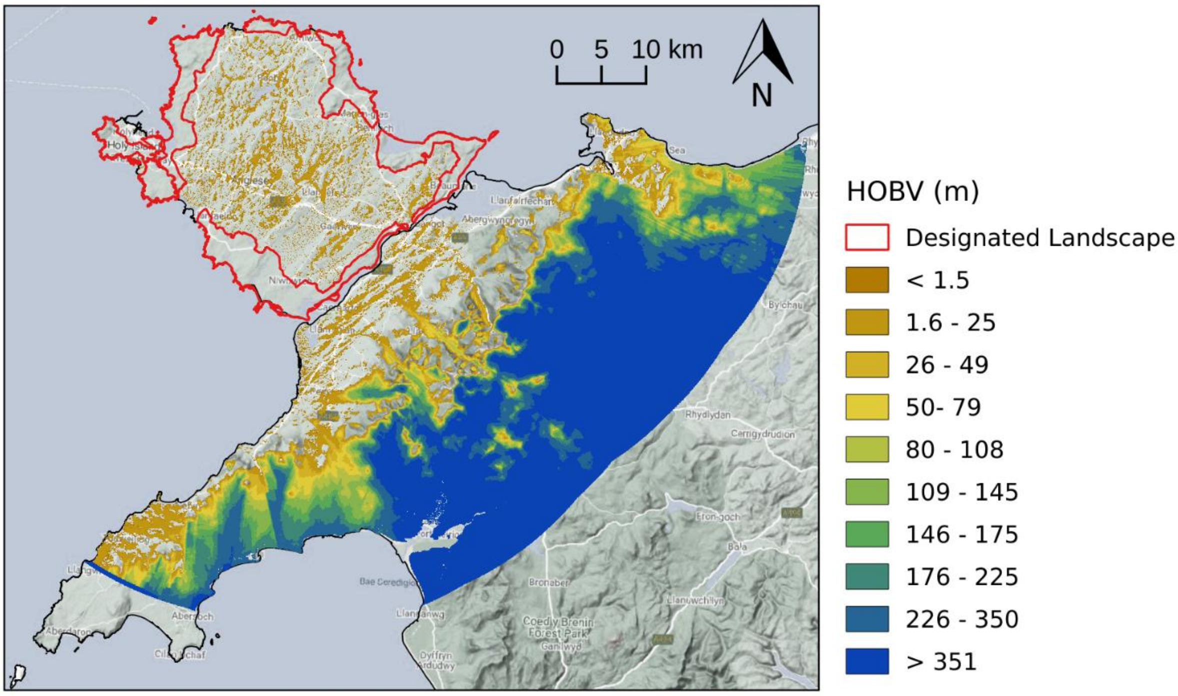


Figure 13. A map of classified HOBV values for regions surrounding the Anglesey AONB.

3.4 Reverse Visibility Analysis

The reverse visibility analysis focused on mapping ZTVs from the perspective of human observers looking into each Designated Landscape from nearby observation points. For each collection of survey points located outside the DL, a ZTV was created and assigned different pixel values depending on whether a visible region intersected with a Designated Landscape (Table 10). This led to the production of 1890 classified rasters for each of the Landscape Areas.

Table 10. A pixel-based classification scheme used for regions of the ZTV that intersected with Designated Landscapes.

Pixel Value	Class
0	Not Visible
1	Rasterised Landscape Area
2	Visible Area not within DL
3	Visible Area within the DL Anglesey
4	Visible Area within the DL Brecon
5	Visible Area within the DL Clwydian
6	Visible Area within the DL Gower
7	Visible Area within the DL Llŷn
8	Visible Area within the DL Pembrokeshire
9	Visible Area within the DL Shropshire
10	Visible Area within the DL Snowdonia
11	Visible Area within the DL Wye

The results from each Landscape Area were then collated to create 9 geospatial datasets that grouped the ZTVs into regions that intersected with each of the Designated Landscapes. ZTVs intersecting a DL were assigned a discrete pixel value (Table 11).

Table 11. Classification scheme to denote if a ZTV intersects with a Designated Landscape.

Pixel Value	Class
0	Not Visible
1	Viewshed within the Designated Landscape
2	Rasterised extent of Landscape Area (viewshed origin)

On the resultant 'reverse-visibility' maps, and indeed any of the maps that illustrate cumulative visibility from multiple observer point, it is important to recognise that the results show visibility from 'somewhere' within that particular landscape area (or DL in the case of the results from Task 2). The area identified as being visible could simply be visible from just one of the observer points used, and therefore may not represent the wider character or pattern of visibility representative of the landscape area (or DL) as a whole.

4. Discussion

It is important to acknowledge that the results of viewshed analysis, presented herein, represent a bare Earth model lacking surface features (such as trees, houses or other large objects) that could obscure a ground view. Furthermore, whilst the Earth's curvature is considered, atmospheric effects (e.g. aerosol optical thickness, water vapour content) and changing weather conditions are unaccounted for within the modelling framework. Our sensitivity analysis revealed that factors such as the spatial resolution of elevation data and the density and distribution of observer points had a moderate impact on viewshed extent, however a larger source of uncertainty relates to the choice of algorithm used to generate the viewsheds. The choice of algorithm may produce viewsheds that vary in extent by as much as ± 10.7 %, whereas the use of different sources of elevation data produces a smaller, but still significant, ± 4.7% change in the viewshed extent.

During this project, detailed discussions were held between GSD and NRW to determine whether the modelled viewsheds accurately represented real-world views achievable from ground positions in each designated landscape. This discussion involved the use of photographs and 3D GIS projections to manually verify the accuracy of the viewsheds based on expert knowledge of the local landscape. It is noted in the literature that the direct validation of viewsheds is seldom feasible in practice due to: (a) the assumption of a bare-Earth model where atmospheric attenuation of sunlight is neglected, (b) occlusion of the viewshed by vegetation, (c) the subjective nature of viewshed extent dependant on observer perceptions, and (d) the cost and impracticality of deploying a team of personnel to manually verify each viewshed (Fisher 1993; Nutsford et al., 2015)[19]. The challenge of viewshed validation was also identified within the Natural England study, where remodelling of the viewsheds with additional observer points was carried out (Murdock et

[19] Fisher, P. F. (1993). Algorithm and implementation uncertainty in viewshed analysis. *International Journal of Geographical Information Science*, *7*(4), 331-347.
Nutsford, D., Reitsma, F., Pearson, A. L., & Kingham, S. (2015). Personalising the viewshed: Visibility analysis from the human perspective. *Applied Geography*, *62*, 1-7.

al., 2013)[20]. Following these discussions, the results from the QGIS model outputs were deemed to better represent ground conditions, therefore all geospatial datasets provided to NRW were generated using this model.

The results of our viewshed analysis over each Designated Landscape is unique in the sense that it combines the modelled viewsheds generated from hundreds or thousands of individual observer points. Our sensitivity analysis revealed that the use of combined observer points can provide reliable and consistent ZTV measurements, with variations in viewshed extent of 1-2% in most Designated Landscapes. These results are almost certainly superior to that which could be achieved from a viewshed analysis using few observer points. Moreover, the synergy of results obtained from multiple viewsheds allows for the impact of potential developments to be considered across all areas surrounding a DL rather than focusing exclusively on small footprint impacts at local scales.

Further work on the sensitivity analysis revealed that the use of a digital terrain model derived from aerial photogrammetry (Ordnance Survey, 2020) produced large errors (> 30 m) in modelled HOBV values. We hypothesise that these errors were caused by a combination of: (a) the lower 50 m spatial resolution of the dataset, and (b) errors in ground elevation over heavily vegetated areas. Since photogrammetry cannot reliably obtain ground elevations over heavily vegetated terrain (Gil *et al*., 2013; Rogers *et al*., 2020)[21], we recommend that all future viewshed analysis be undertaken with a LiDAR-derived terrain model where data availability permits. It should also be stressed that the viewshed analysis was conducted at a spatial resolution of 30 m, consequently data users should be aware that it may be inappropriate to utilise these products to infer visibility or HOBV at finer spatial scales.

The results presented in this report are intended to provide initial estimates of viewshed extent and the height at which objects become visible from key observer locations throughout Wales. The geospatial data are intended to inform planning policy and serve as strategic layers for NRW, the public and other organisations. The datasets are not intended to replace detailed ground-based assessments of visibility that can only be obtained through local site surveys. However, they provide an initial appraisal / screening tool for developments that NRW are regularly consulted upon.

5. Conclusion

In summary, a major national study was undertaken to estimate landscape visibility from the perspective of human observers located at key vantage points throughout Wales. The study primarily focused on mapping Zones of Theoretical Visibility across nine Designated Landscapes from the perspectives of human observers looking out from each Designated

[20] Murdock et al., 2013, GIS Viewshed Analysis to Identify Zones of Potential Visual Impact on Protected Landscapes: A Natural England project. Available at http://www.geodata.soton.ac.uk/geodata/viewshed/

[21] Gil, A. L., Núñez-Casillas, L., Isenburg, M., et al. (2013). A comparison between LiDAR and photogrammetry digital terrain models in a forest area on Tenerife Island. *Canadian Journal of Remote Sensing*, *39*(5), 396-409.
Rogers, S. R., Manning, I., & Livingstone, W. (2020). Comparing the spatial accuracy of Digital Surface Models from four unoccupied aerial systems: Photogrammetry versus LiDAR. *Remote Sensing*, *12*(17), 2806.

Landscape into the surrounding countryside, and looking into each Designated Landscape from prominent vantage points located outside of the nine protected landscapes.

This analysis provided information on landscape visibility and the estimated heights at which objects become visible to human observers for 99.3% of the country. Indeed, only 155 km^2, or 0.7% of the country's total land area, was not covered by this analysis.

This work led to the production of several geospatial datasets that are intended to be distributed freely to the public on NRW's open data portal Lle, allowing users to utilise the data to form an initial appraisal of the potential scenic impacts incurred by new construction projects. The datasets are not intended to replace detailed ground-based assessments of visibility, however they are intended to serve as a rapid screening tool for a range of stakeholders.

The first set of deliverables includes the results of viewshed analysis for prominent viewpoints throughout Wales that are regularly visited by the public. The second and third group of deliverables includes the results of viewshed analysis performed for nine Designated Landscapes within Wales. For each group of deliverables, GSD has provided NRW with three types of geospatial layers:

a. a binary viewshed demarcating the Zone of Theoretical Visibility from the observer point(s),
b. a frequency occurrence layer, or heatmap, showing regions visible from multiple observer points, and
c. a layer containing the estimated heights (in metres above ground level) that objects would need to acquire to become visible to a human observer located at the obersver point(s).

All analyses were undertaken using a 30 m digital terrain model sourced from the NASA Shuttle Radar Topography Mission (Van Zyl, 2001). This dataset is not restricted by licensing requirements, thereby allowing project deliverables to be distributed freely on NRW websites and through other channels.

Finally, we would like to acknowledge the previous work of Murdock *et al*. (2013), which served as a key reference point for the work carried out in this study. We would also like to thank NRW staff whose guidance and local expertise was critical in identifying key viewpoints throughout Wales and in evaluating the accuracy of viewsheds generated using different models. In particular, we are grateful to John Briggs of NRW for his expert guidance throughout the duration of this project.

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Glossary and abbreviations

AONB Area of Outstanding Natural Beauty

DEM Digital Elevation Model

DL Designated Landscape

DTM Digital Terrain Model

GIS Geographical Information System

GSD Geo Smart Decisions

GPS Global Positioning System

HOBV Height Objects Become Visible

LiDAR Light Detection and Ranging

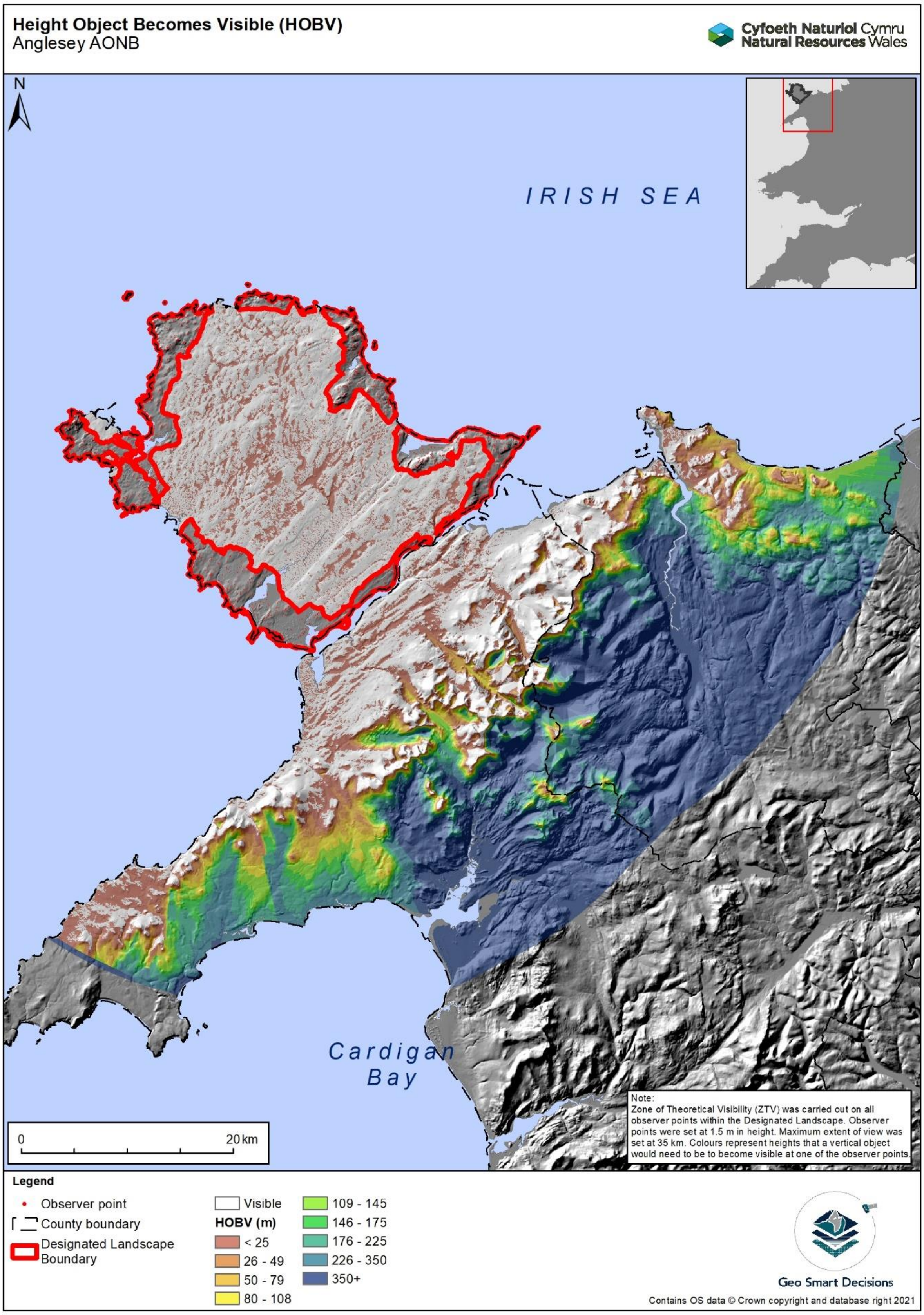
OS Ordnance Survey

QGIS Quantum Geographical Information System

SRTM Shuttle Radar Topography Mission

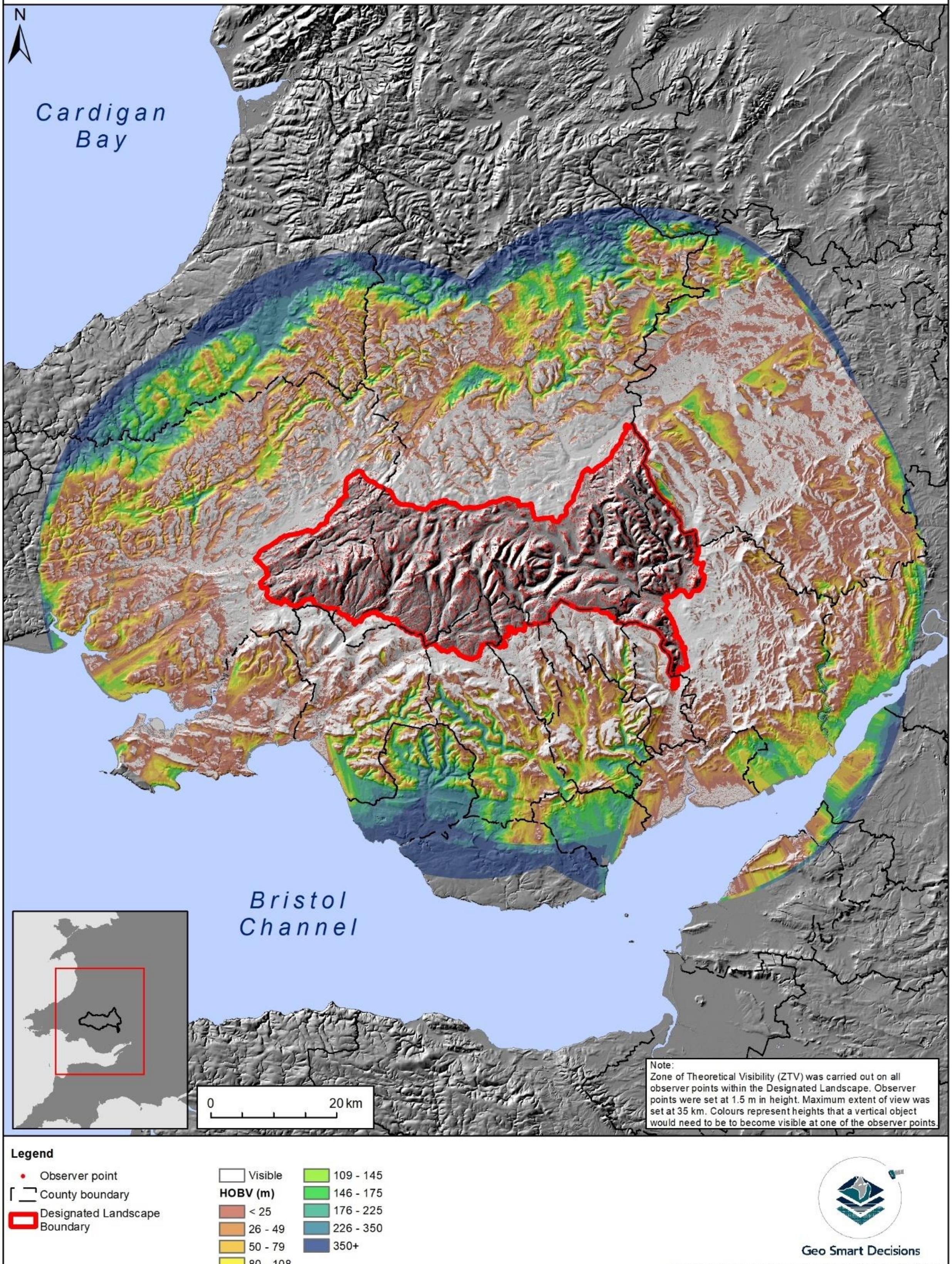
ZTV Zone of Theoretical Visibility

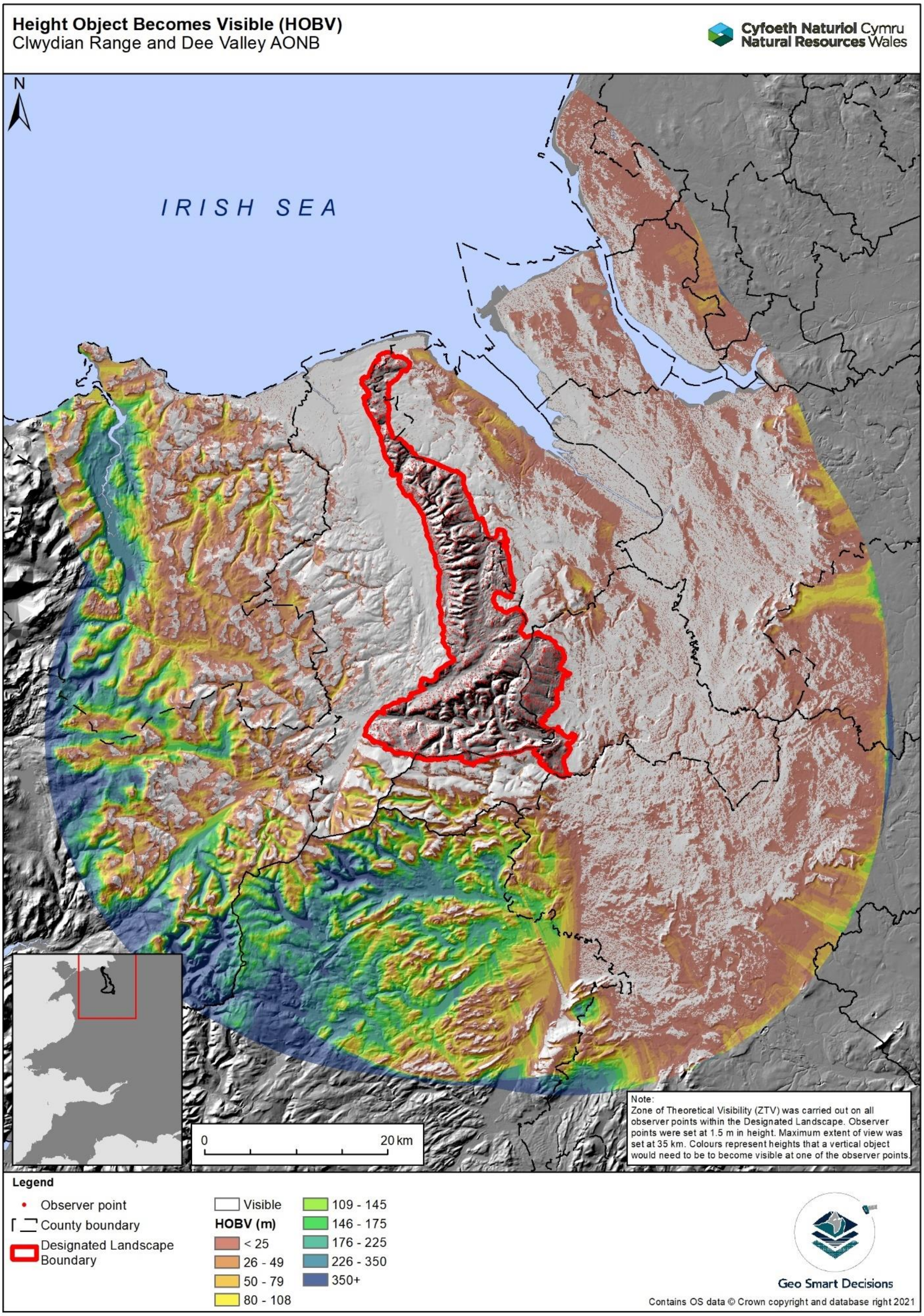
Appendix 1: HOBV Map



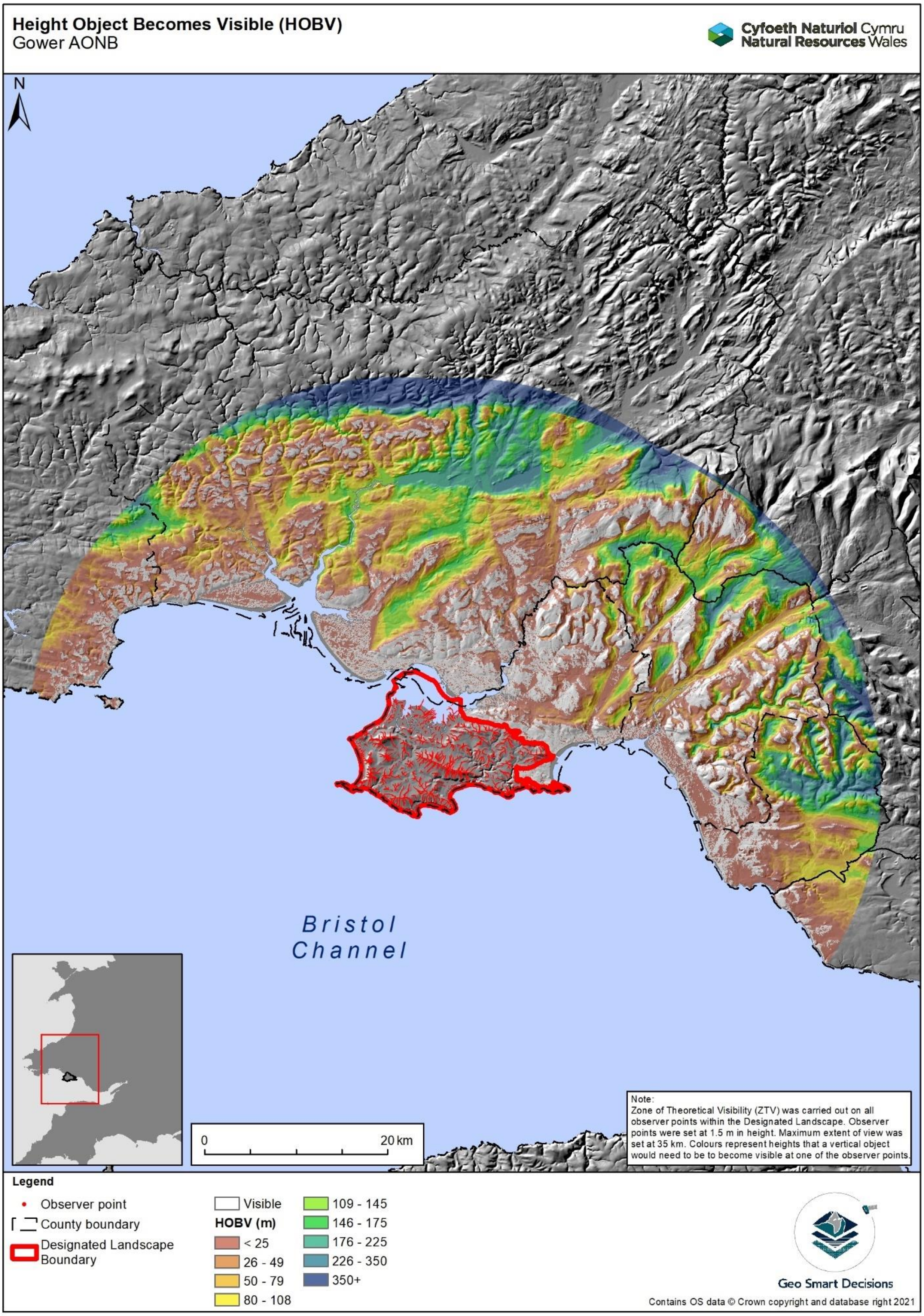
Height Object Becomes Visible (HOBV)
Brecon Beacons National Park

Cyfoeth Naturiol Cymru
Natural Resources Wales

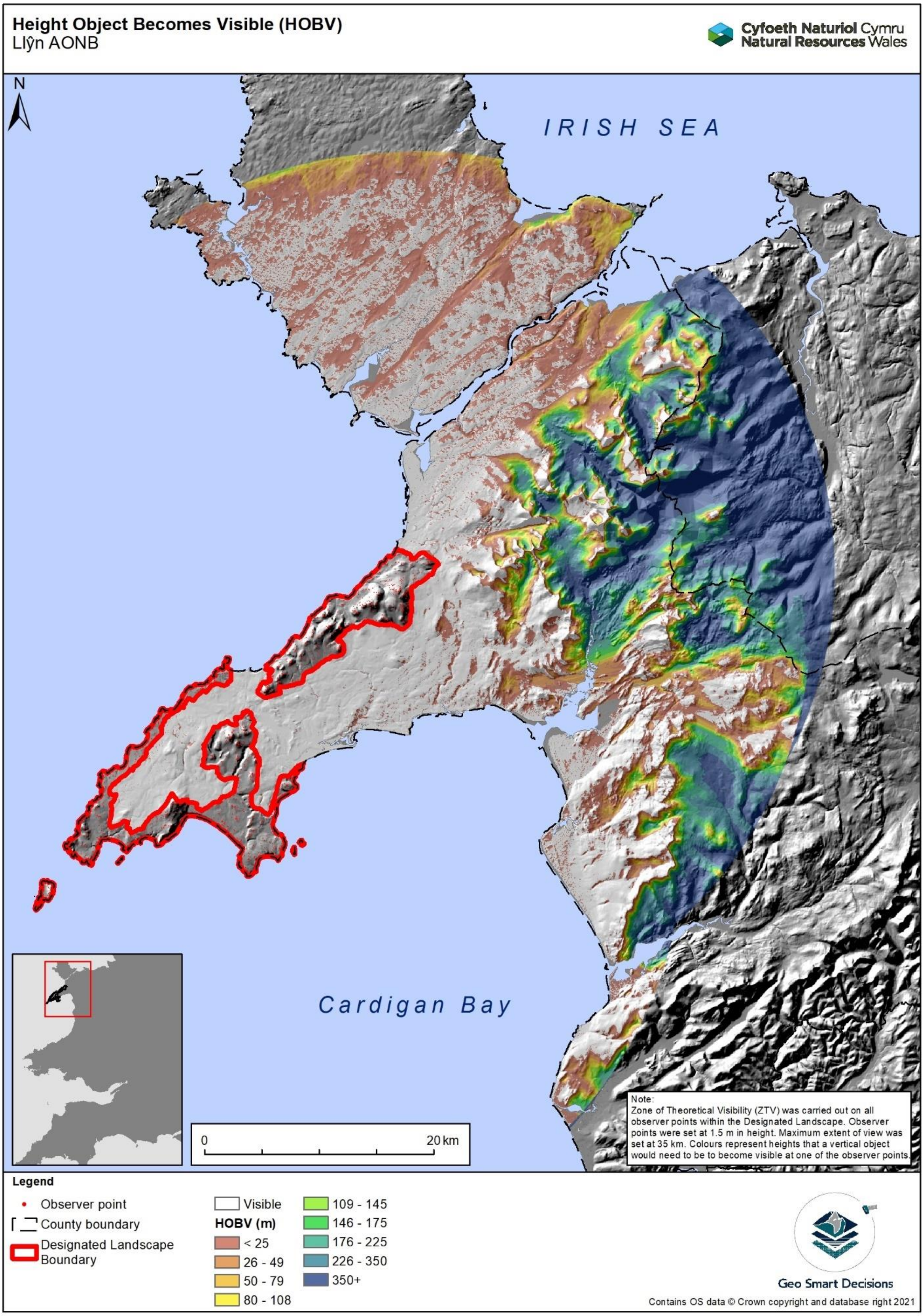


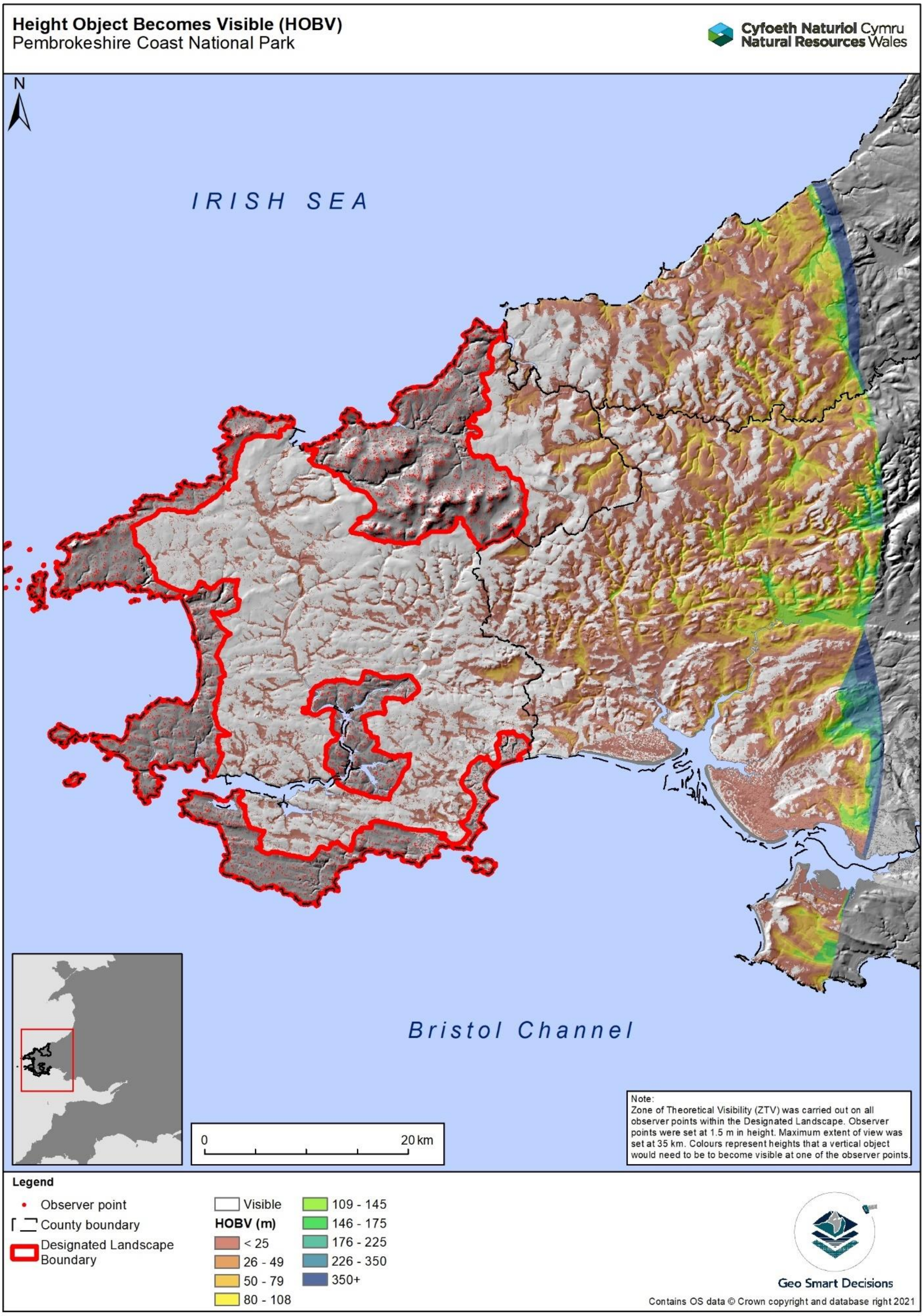


Height Object Becomes Visible (HOBV)
Clwydian Range and Dee Valley AONB
Cyfoeth Naturiol Cymru
Natural Resources Wales
N
IRISH SEA
0
20 km
Note:
Zone of Theoretical Visibility (ZTV) was carried out on all observer points within the Designated Landscape. Observer points were set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent heights that a vertical object would need to be to become visible at one of the observer points.
Legend
Observer point
County boundary
Designated Landscape Boundary
Visible
HOBV (m)
< 25
26 - 49
50 - 79
80 - 108
109 - 145
146 - 175
176 - 225
226 - 350
350+
Geo Smart Decisions
Contains OS data © Crown copyright and database right 2021



Height Object Becomes Visible (HOBV)
Gower AONB
Cyfoeth Naturiol Cymru
Natural Resources Wales
N
Bristol Channel
0
20 km
Note:
Zone of Theoretical Visibility (ZTV) was carried out on all observer points within the Designated Landscape. Observer points were set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent heights that a vertical object would need to be to become visible at one of the observer points.
Legend
Observer point
County boundary
Designated Landscape Boundary
Visible
HOBV (m)
< 25
26 - 49
50 - 79
80 - 108
109 - 145
146 - 175
176 - 225
226 - 350
350+
Geo Smart Decisions
Contains OS data © Crown copyright and database right 2021

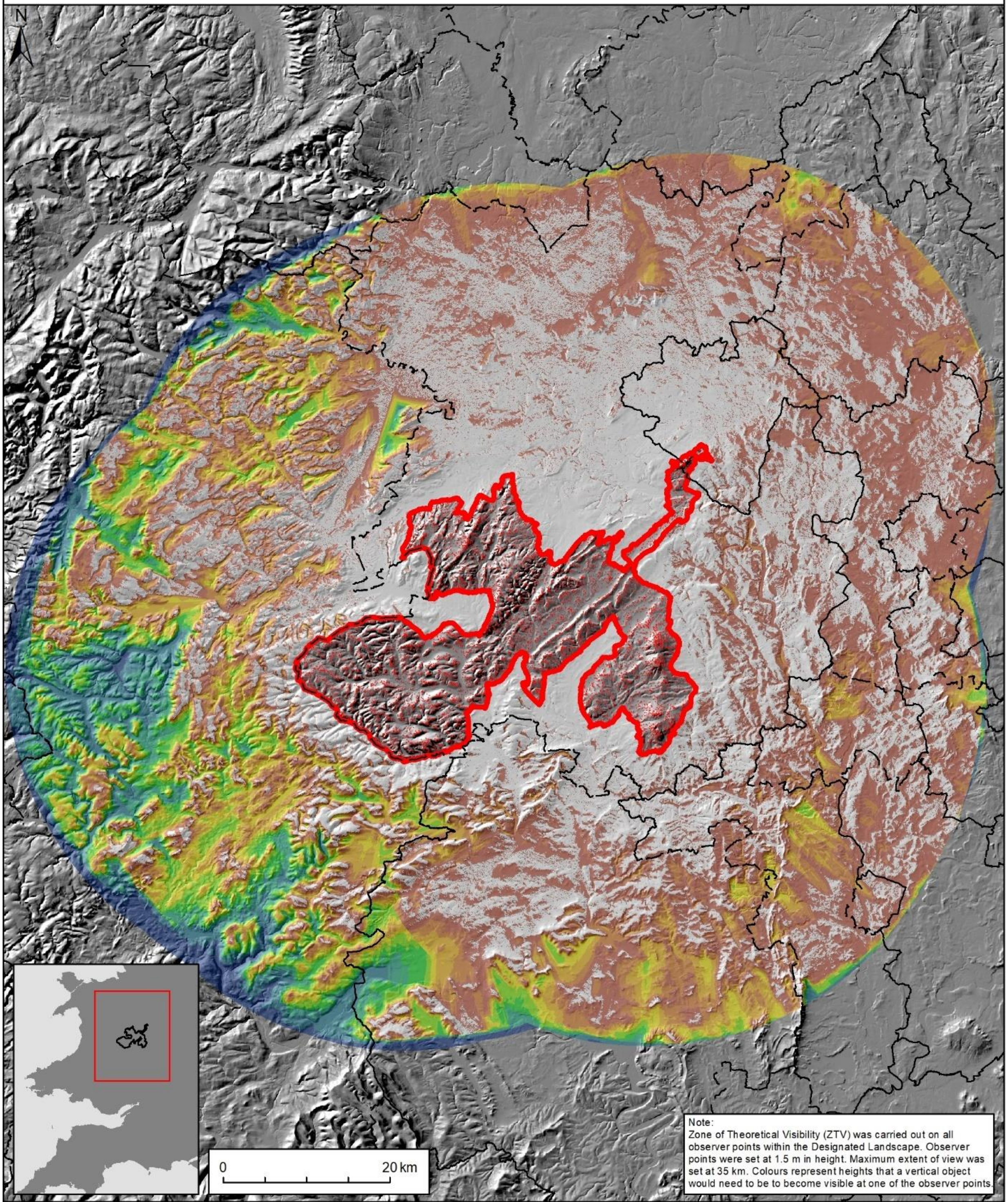

Height Object Becomes Visible (HOBV)
Llŷn AONB
Cyfoeth Naturiol Cymru
Natural Resources Wales
N
IRISH SEA
Cardigan Bay
0
20 km
Note:
Zone of Theoretical Visibility (ZTV) was carried out on all observer points within the Designated Landscape. Observer points were set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent heights that a vertical object would need to be to become visible at one of the observer points.
Legend
Observer point
County boundary
Designated Landscape Boundary
Visible
HOBV (m)
< 25
26 - 49
50 - 79
80 - 108
109 - 145
146 - 175
176 - 225
226 - 350
350+
Geo Smart Decisions
Contains OS data © Crown copyright and database right 2021



Height Object Becomes Visible (HOBV)
Pembrokeshire Coast National Park
Cyfoeth Naturiol Cymru
Natural Resources Wales
N
IRISH SEA
Bristol Channel
0
20 km
Note:
Zone of Theoretical Visibility (ZTV) was carried out on all observer points within the Designated Landscape. Observer points were set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent heights that a vertical object would need to be to become visible at one of the observer points.
Legend
Observer point
County boundary
Designated Landscape Boundary
Visible
HOBV (m)
< 25
26 - 49
50 - 79
80 - 108
109 - 145
146 - 175
176 - 225
226 - 350
350+
Geo Smart Decisions
Contains OS data © Crown copyright and database right 2021

Height Object Becomes Visible (HOBV)
Shropshire Hills AONB

Cyfoeth Naturiol Cymru
Natural Resources Wales



Legend

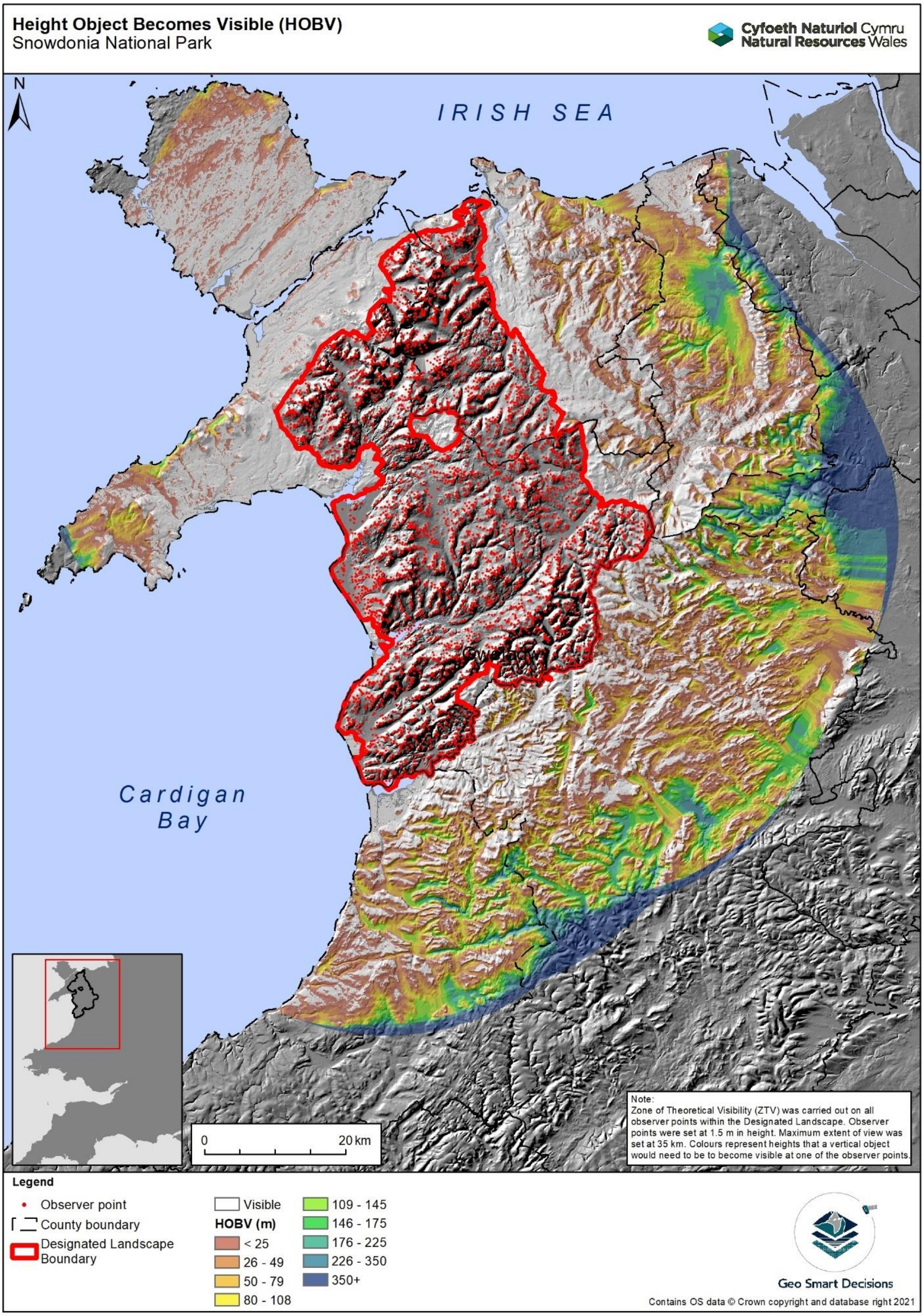
- Observer point
- County boundary
- Designated Landscape Boundary

Visible

HOBV (m)

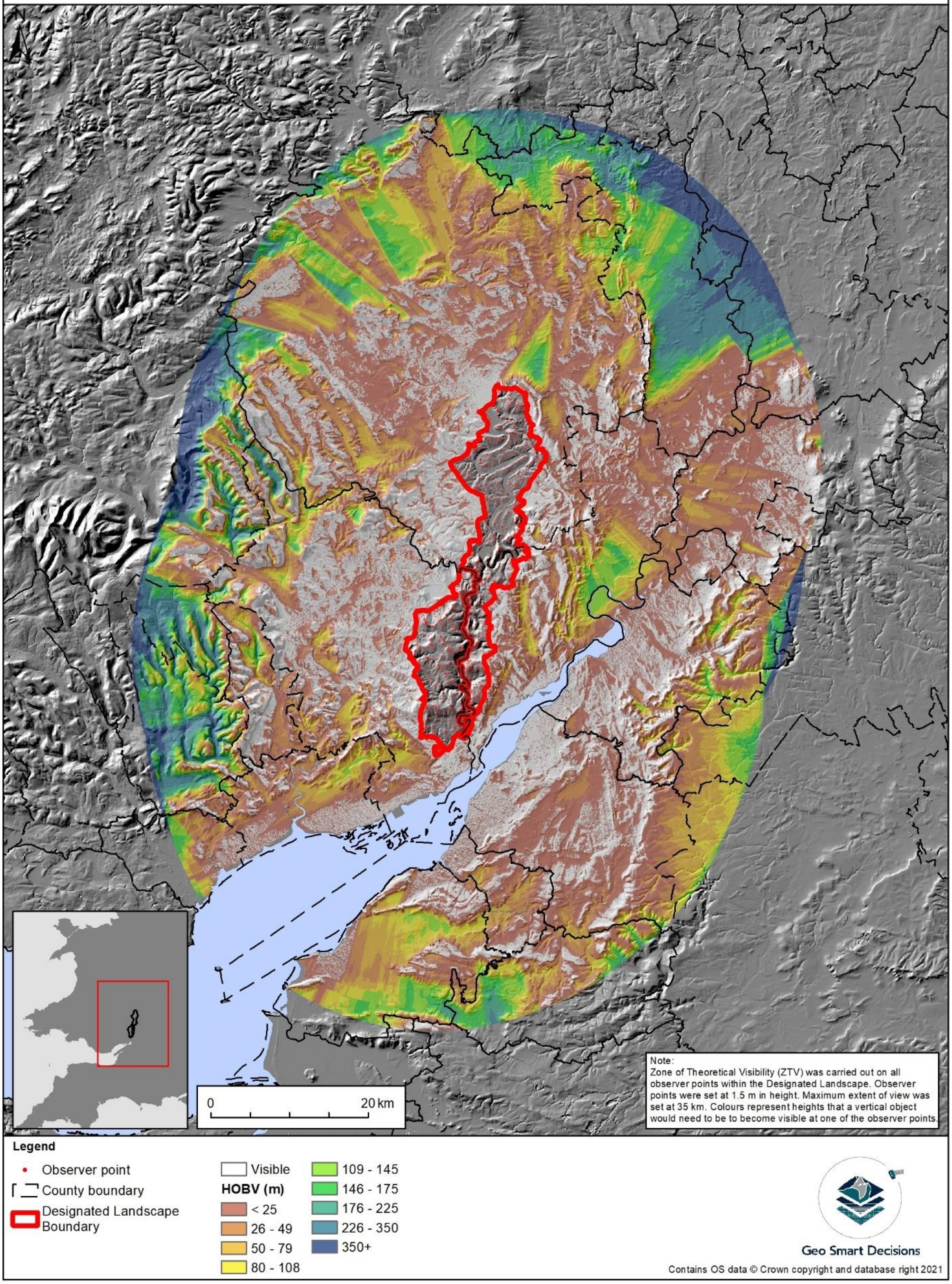
- < 25
- 26 - 49
- 50 - 79
- 80 - 108
- 109 - 145
- 146 - 175
- 176 - 225
- 226 - 350
- 350+

Geo Smart Decisions

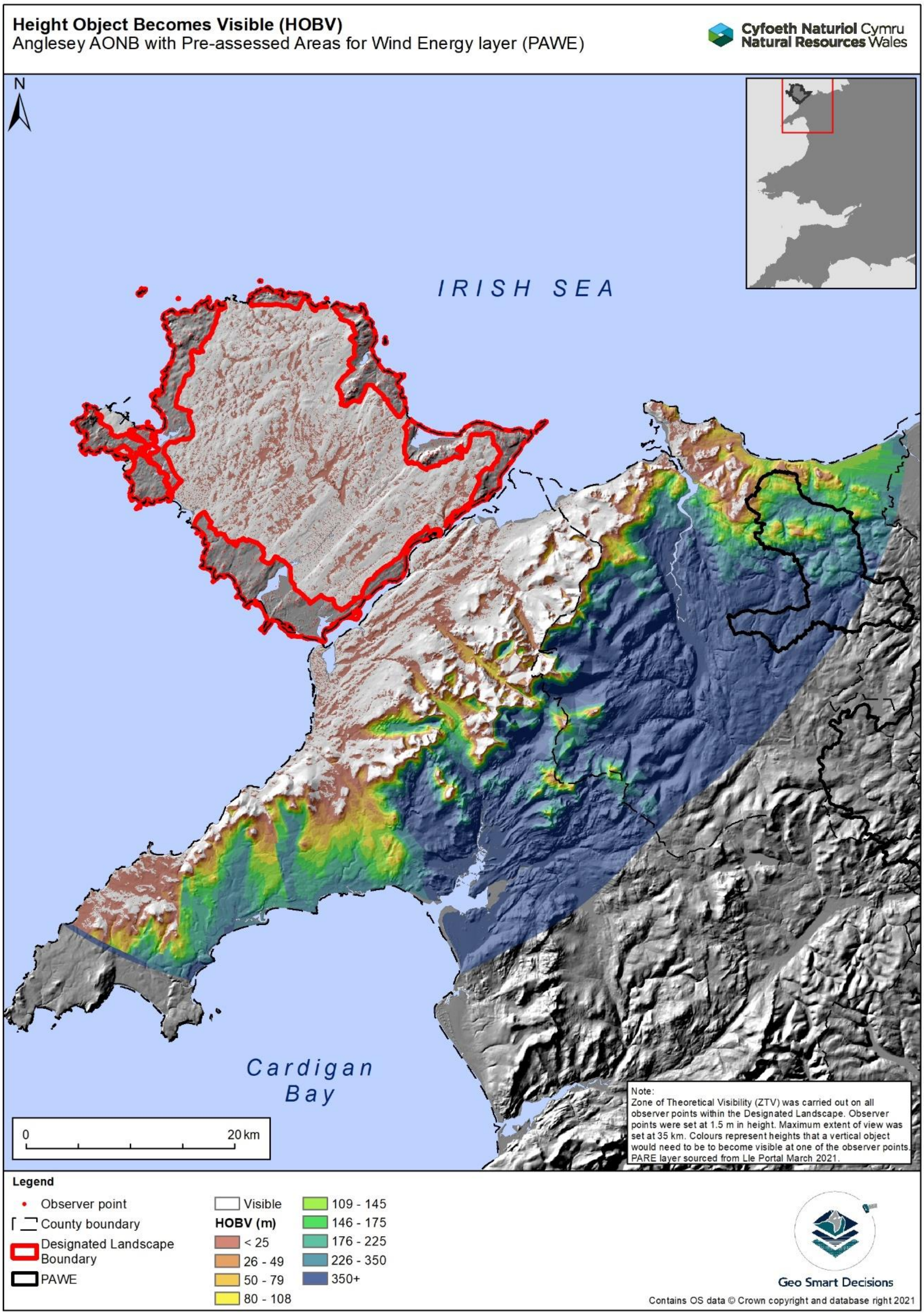

Height Object Becomes Visible (HOBV)
Snowdonia National Park
Cyfoeth Naturiol Cymru
Natural Resources Wales
N
IRISH SEA
Cardigan Bay
0
20 km
Note:
Zone of Theoretical Visibility (ZTV) was carried out on all observer points within the Designated Landscape. Observer points were set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent heights that a vertical object would need to be to become visible at one of the observer points.
Legend
Observer point
County boundary
Designated Landscape Boundary
Visible
HOBV (m)
< 25
26 - 49
50 - 79
80 - 108
109 - 145
146 - 175
176 - 225
226 - 350
350+
Geo Smart Decisions
Contains OS data © Crown copyright and database right 2021

Height Object Becomes Visible (HOBV)
Wye Valley AONB

Cyfoeth Naturiol Cymru
Natural Resources Wales

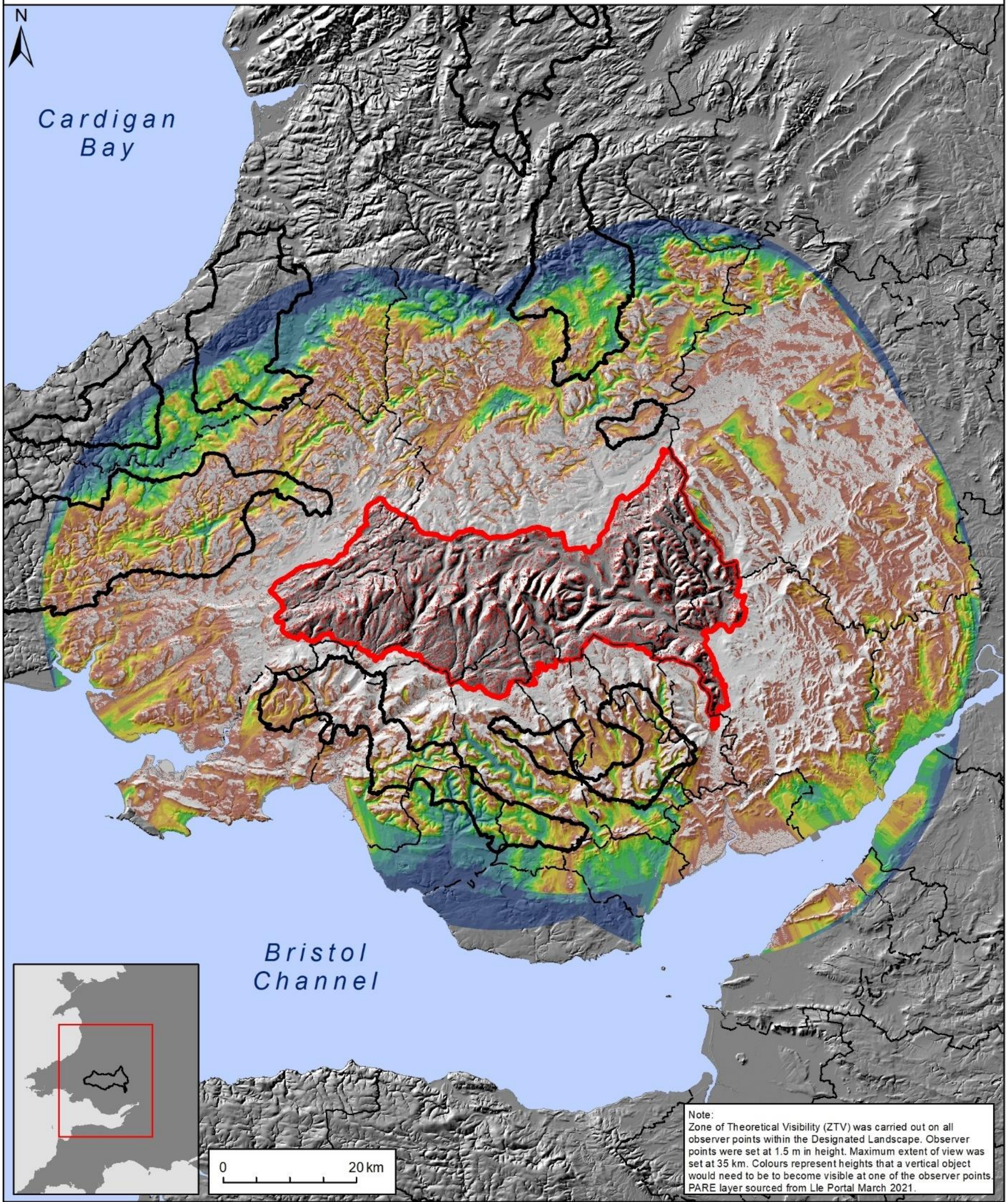


Appendix 2: HOBV Maps with PAWE layers



Height Object Becomes Visible (HOBV)
Brecon Beacons National Park with Pre-assessed Areas for Wind Energy layer (PAWE)

Cyfoeth Naturiol Cymru
Natural Resources Wales



Legend

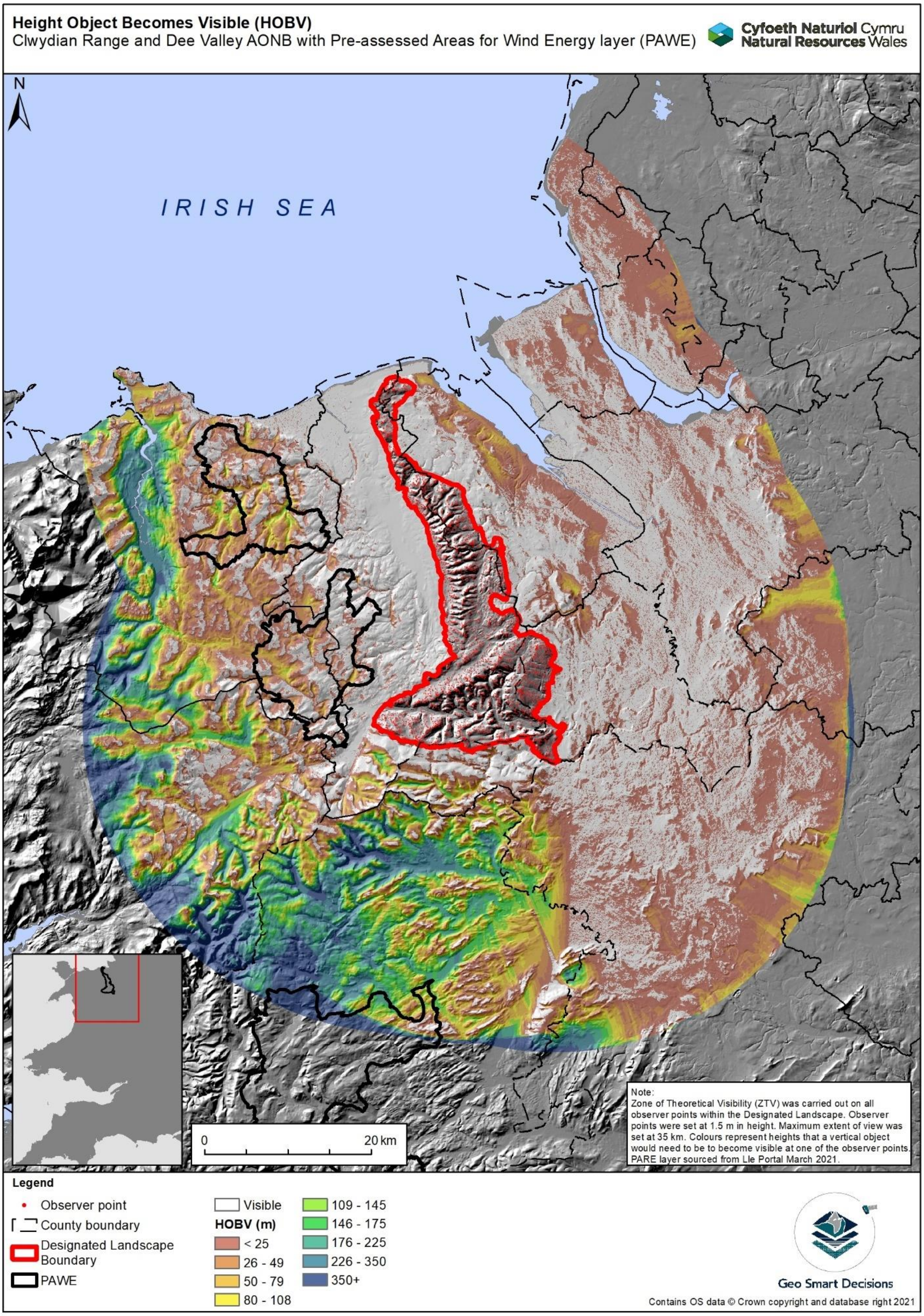
- Observer point
- County boundary
- Designated Landscape Boundary
- PAWE

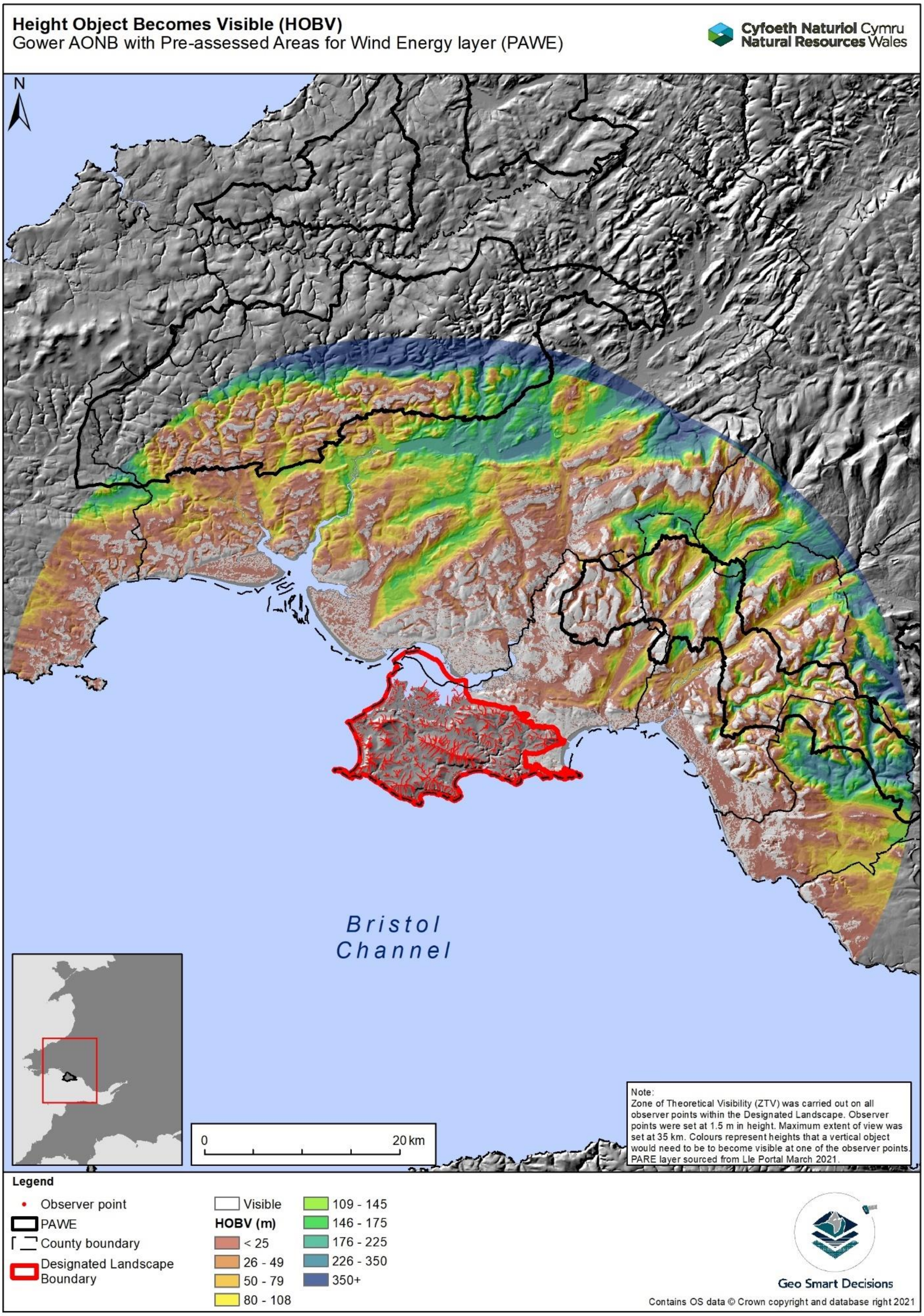
Visible

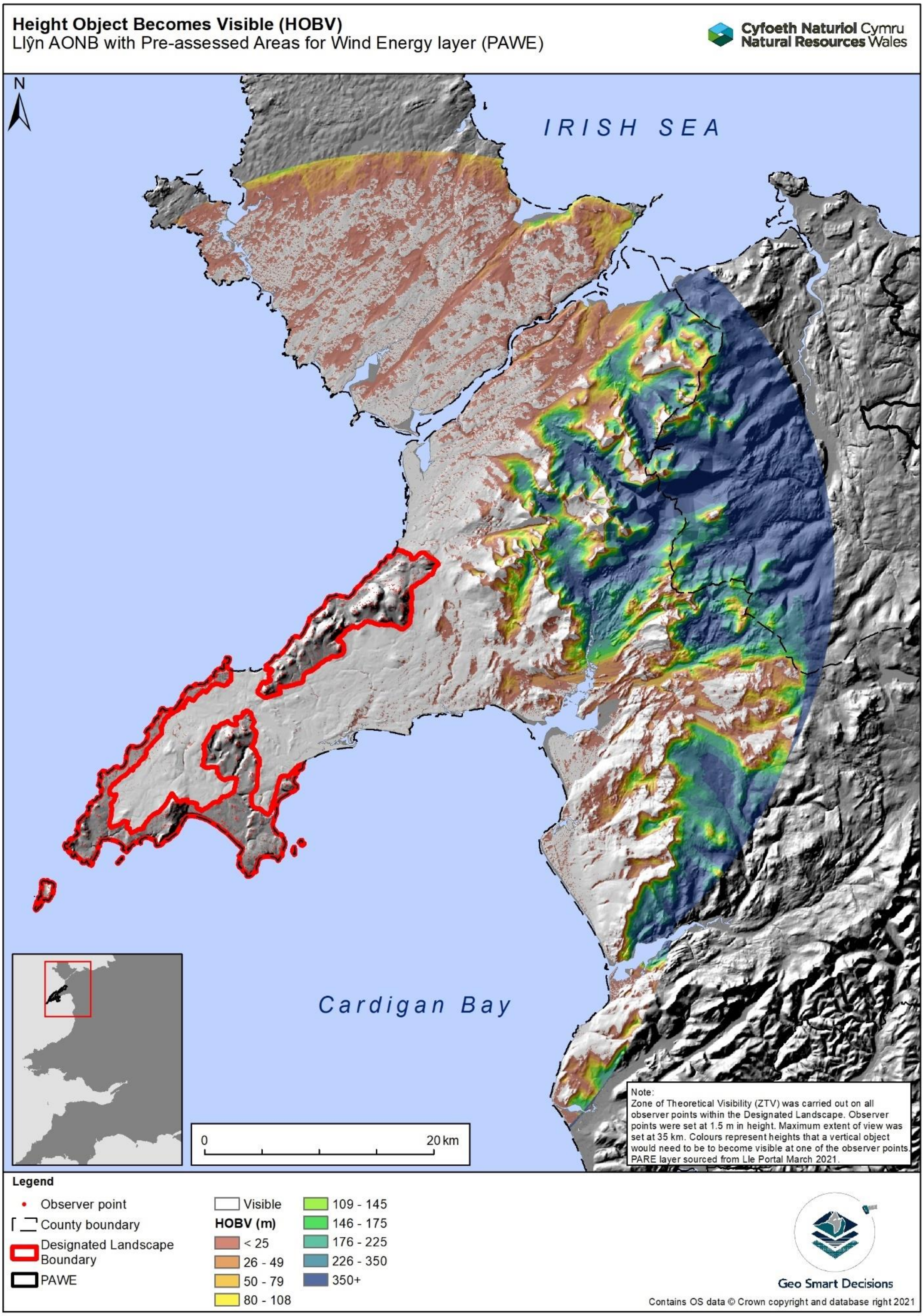
HOBV (m)

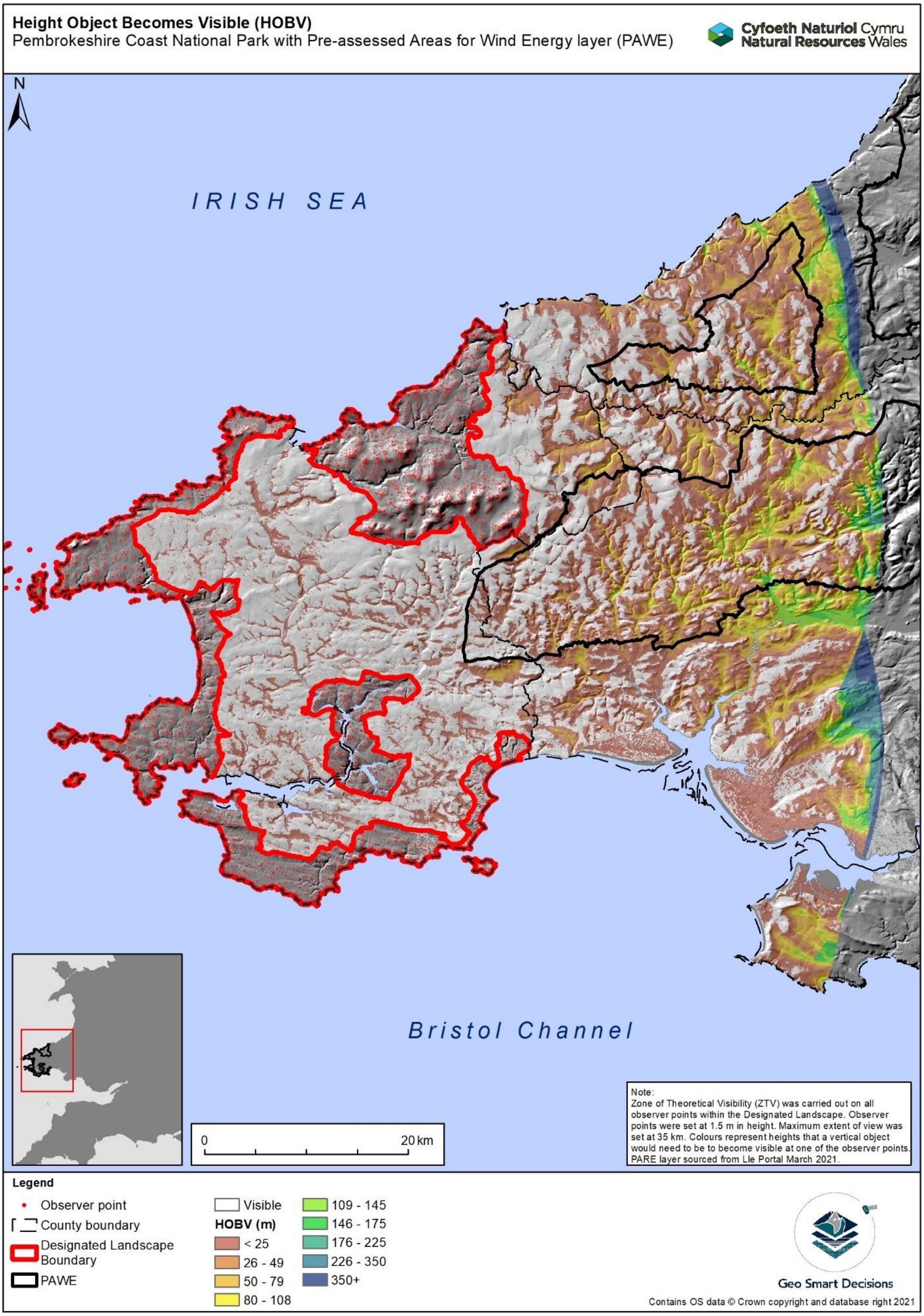
- < 25
- 26 - 49
- 50 - 79
- 80 - 108
- 109 - 145
- 146 - 175
- 176 - 225
- 226 - 350
- 350+

Geo Smart Decisions


Height Object Becomes Visible (HOBV)
Clwydian Range and Dee Valley AONB with Pre-assessed Areas for Wind Energy layer (PAWE)
Cyfoeth Naturiol Cymru
Natural Resources Wales
N
IRISH SEA
0
20 km
Note:
Zone of Theoretical Visibility (ZTV) was carried out on all observer points within the Designated Landscape. Observer points were set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent heights that a vertical object would need to be to become visible at one of the observer points. PARE layer sourced from Lle Portal March 2021.
Legend
Observer point
County boundary
Designated Landscape Boundary
PAWE
Visible
HOBV (m)
< 25
26 - 49
50 - 79
80 - 108
109 - 145
146 - 175
176 - 225
226 - 350
350+
Geo Smart Decisions
Contains OS data © Crown copyright and database right 2021

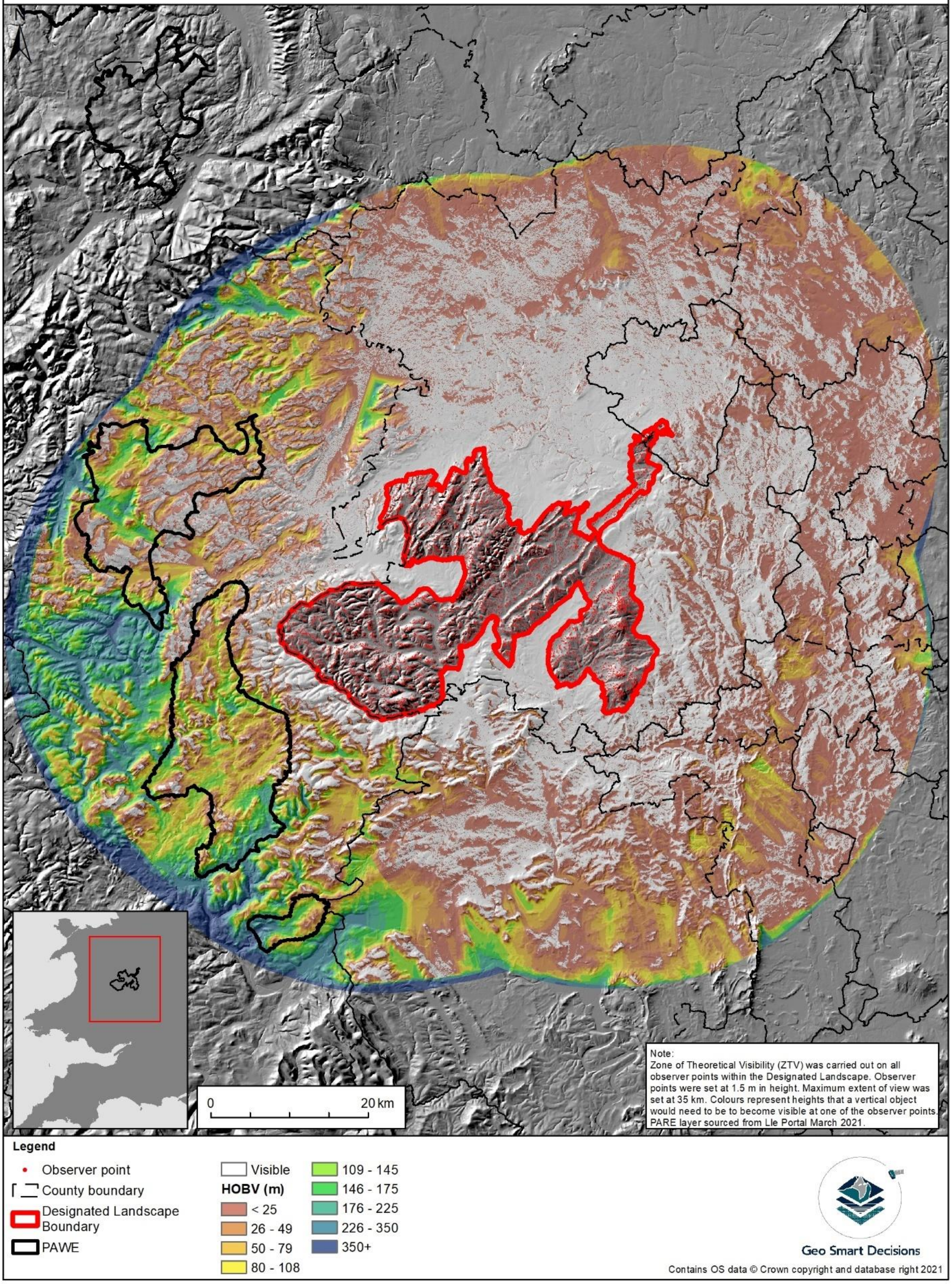

Height Object Becomes Visible (HOBV)
Gower AONB with Pre-assessed Areas for Wind Energy layer (PAWE)
Cyfoeth Naturiol Cymru
Natural Resources Wales
N
Bristol Channel
0
20 km
Note:
Zone of Theoretical Visibility (ZTV) was carried out on all observer points within the Designated Landscape. Observer points were set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent heights that a vertical object would need to be to become visible at one of the observer points. PARE layer sourced from Lle Portal March 2021.
Legend
Observer point
PAWE
County boundary
Designated Landscape Boundary
Visible
HOBV (m)
< 25
26 - 49
50 - 79
80 - 108
109 - 145
146 - 175
176 - 225
226 - 350
350+
Geo Smart Decisions
Contains OS data © Crown copyright and database right 2021

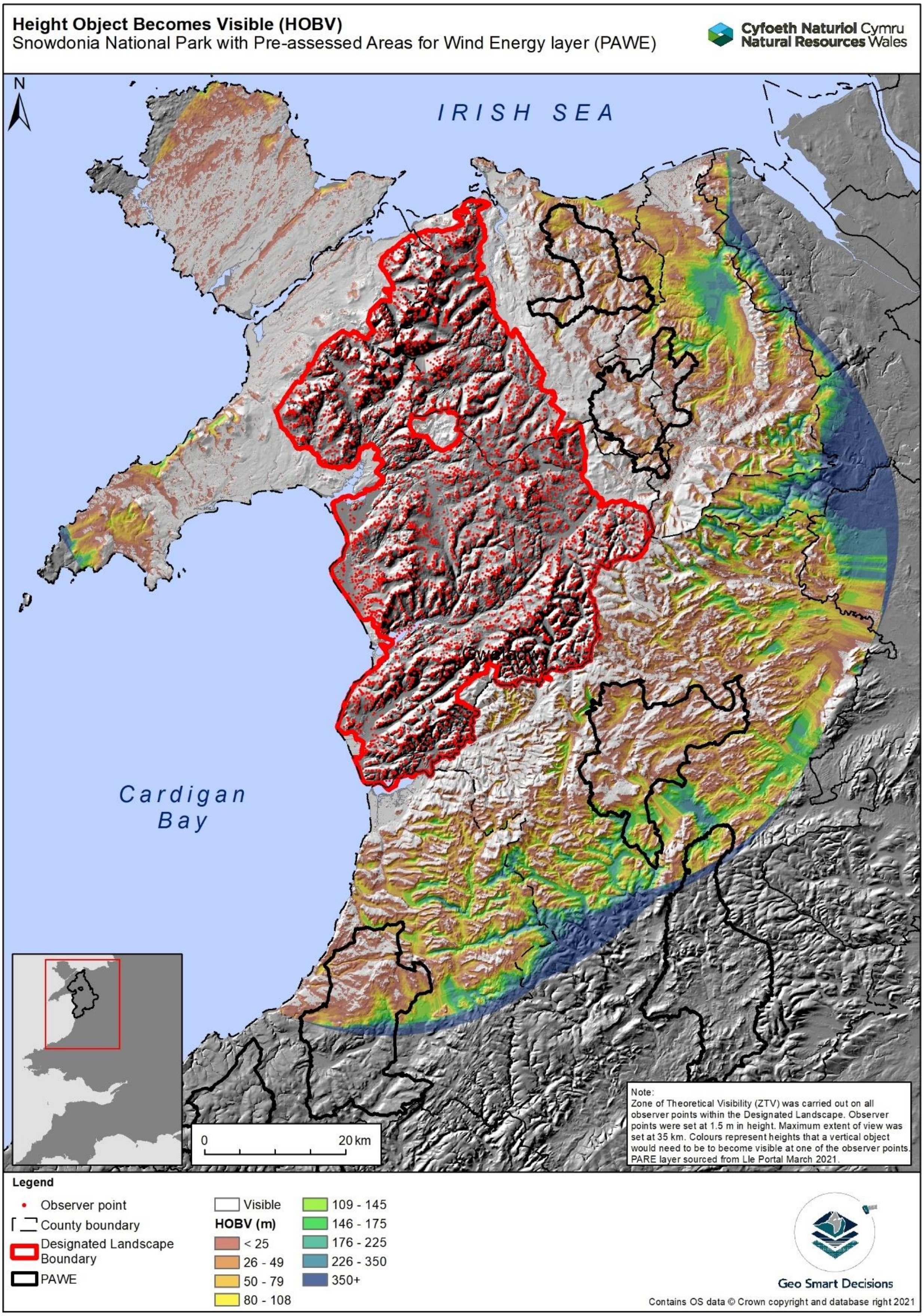

Height Object Becomes Visible (HOBV)
Llŷn AONB with Pre-assessed Areas for Wind Energy layer (PAWE)
Cyfoeth Naturiol Cymru
Natural Resources Wales
N
IRISH SEA
Cardigan Bay
0
20 km
Note:
Zone of Theoretical Visibility (ZTV) was carried out on all observer points within the Designated Landscape. Observer points were set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent heights that a vertical object would need to be to become visible at one of the observer points. PARE layer sourced from Lle Portal March 2021.
Legend
Observer point
County boundary
Designated Landscape Boundary
PAWE
Visible
HOBV (m)
< 25
26 - 49
50 - 79
80 - 108
109 - 145
146 - 175
176 - 225
226 - 350
350+
Geo Smart Decisions
Contains OS data © Crown copyright and database right 2021


Height Object Becomes Visible (HOBV)
Pembrokeshire Coast National Park with Pre-assessed Areas for Wind Energy layer (PAWE)
Cyfoeth Naturiol Cymru
Natural Resources Wales
N
IRISH SEA
Bristol Channel
0
20 km
Note:
Zone of Theoretical Visibility (ZTV) was carried out on all observer points within the Designated Landscape. Observer points were set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent heights that a vertical object would need to be to become visible at one of the observer points. PARE layer sourced from Lle Portal March 2021.
Legend
Observer point
County boundary
Designated Landscape Boundary
PAWE
Visible
HOBV (m)
< 25
26 - 49
50 - 79
80 - 108
109 - 145
146 - 175
176 - 225
226 - 350
350+
Geo Smart Decisions
Contains OS data © Crown copyright and database right 2021

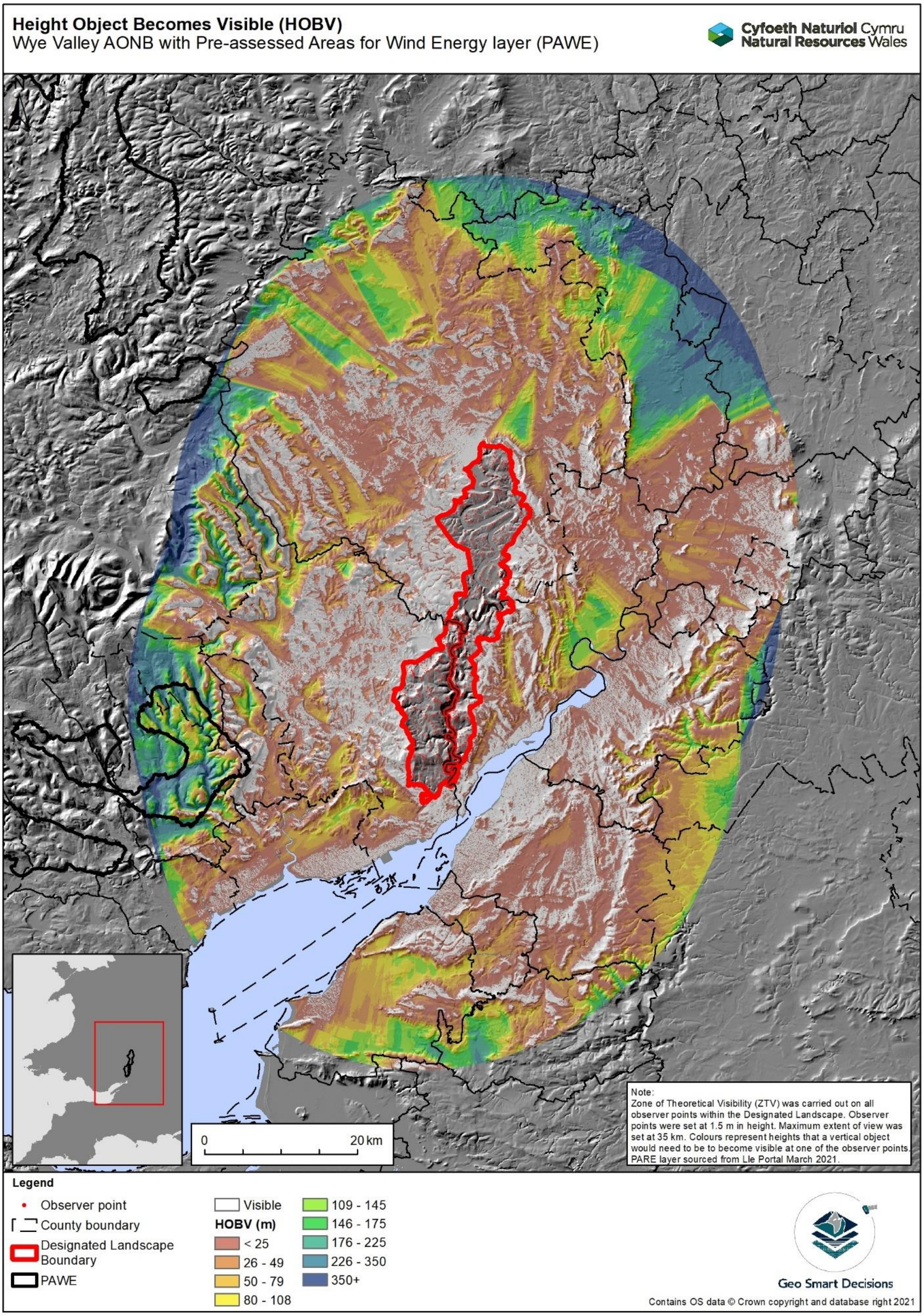
Height Object Becomes Visible (HOBV)
Shropshire Hills AONB with Pre-assessed Areas for Wind Energy layer (PAWE)

Cyfoeth Naturiol Cymru
Natural Resources Wales

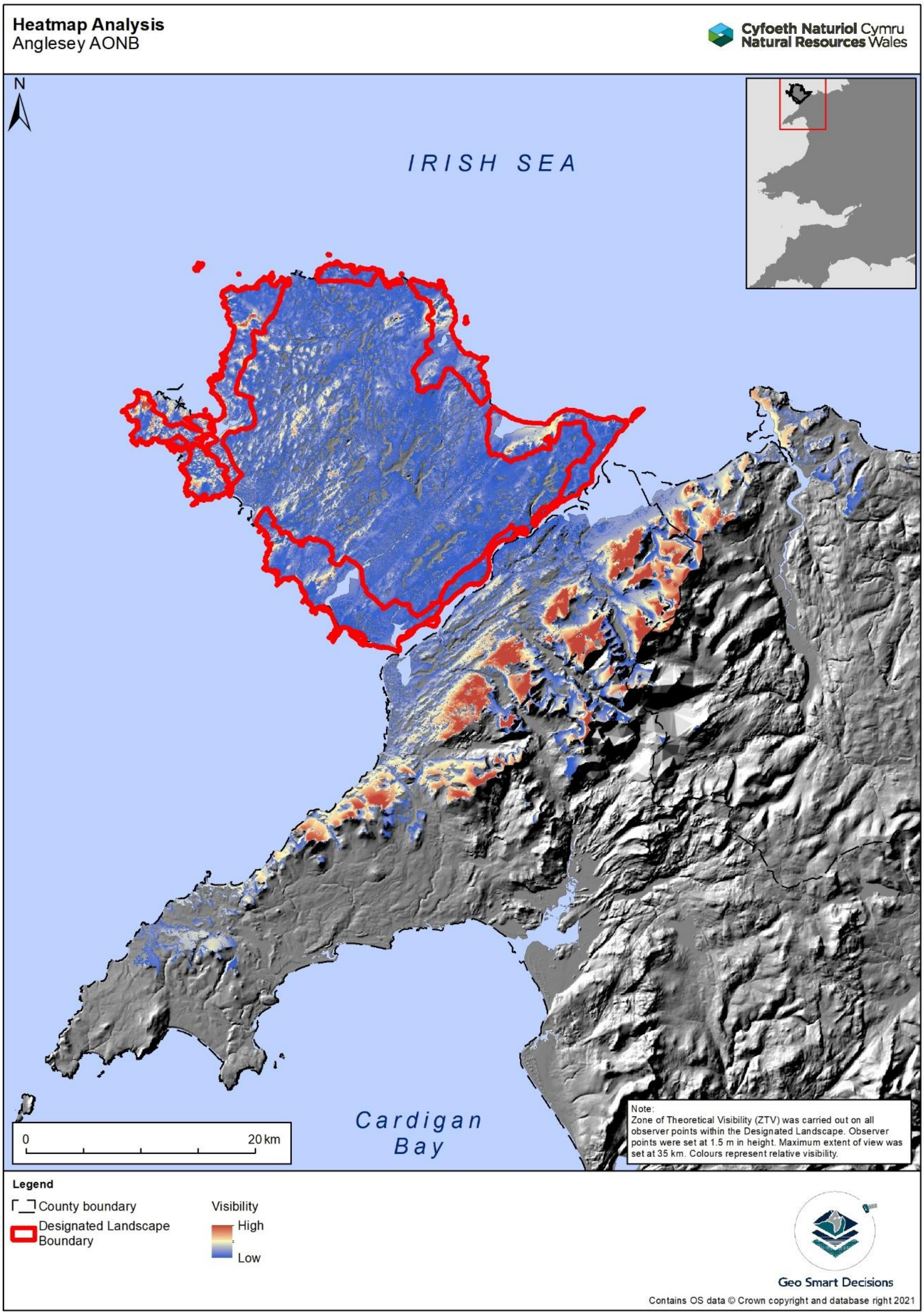


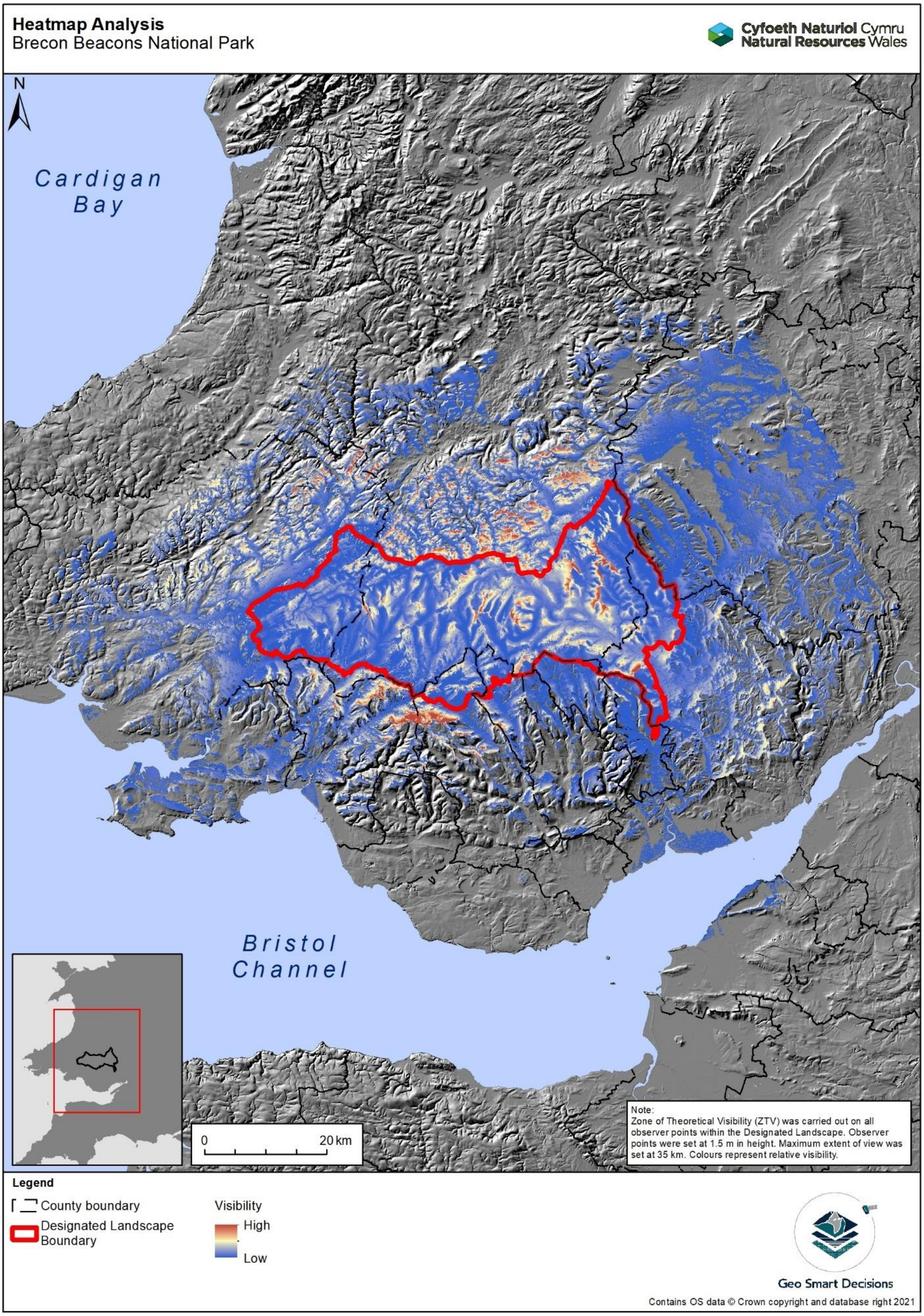


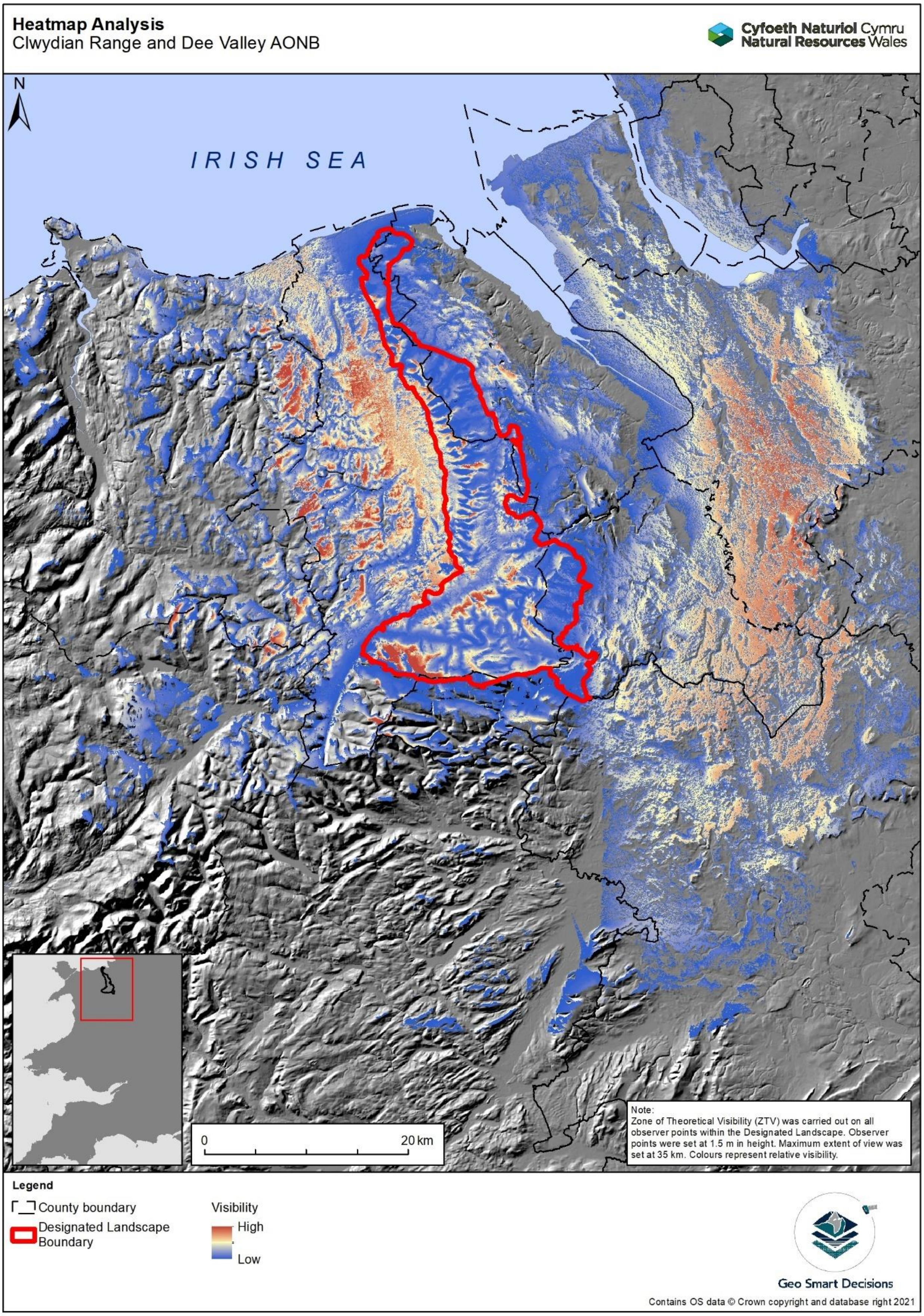
Height Object Becomes Visible (HOBV)
Snowdonia National Park with Pre-assessed Areas for Wind Energy layer (PAWE)
Cyfoeth Naturiol Cymru
Natural Resources Wales
N
IRISH SEA
Cardigan Bay
0
20 km
Note:
Zone of Theoretical Visibility (ZTV) was carried out on all observer points within the Designated Landscape. Observer points were set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent heights that a vertical object would need to be to become visible at one of the observer points. PARE layer sourced from Lle Portal March 2021.
Legend
Observer point
County boundary
Designated Landscape Boundary
PAWE
Visible
HOBV (m)
< 25
26 - 49
50 - 79
80 - 108
109 - 145
146 - 175
176 - 225
226 - 350
350+
Geo Smart Decisions
Contains OS data © Crown copyright and database right 2021

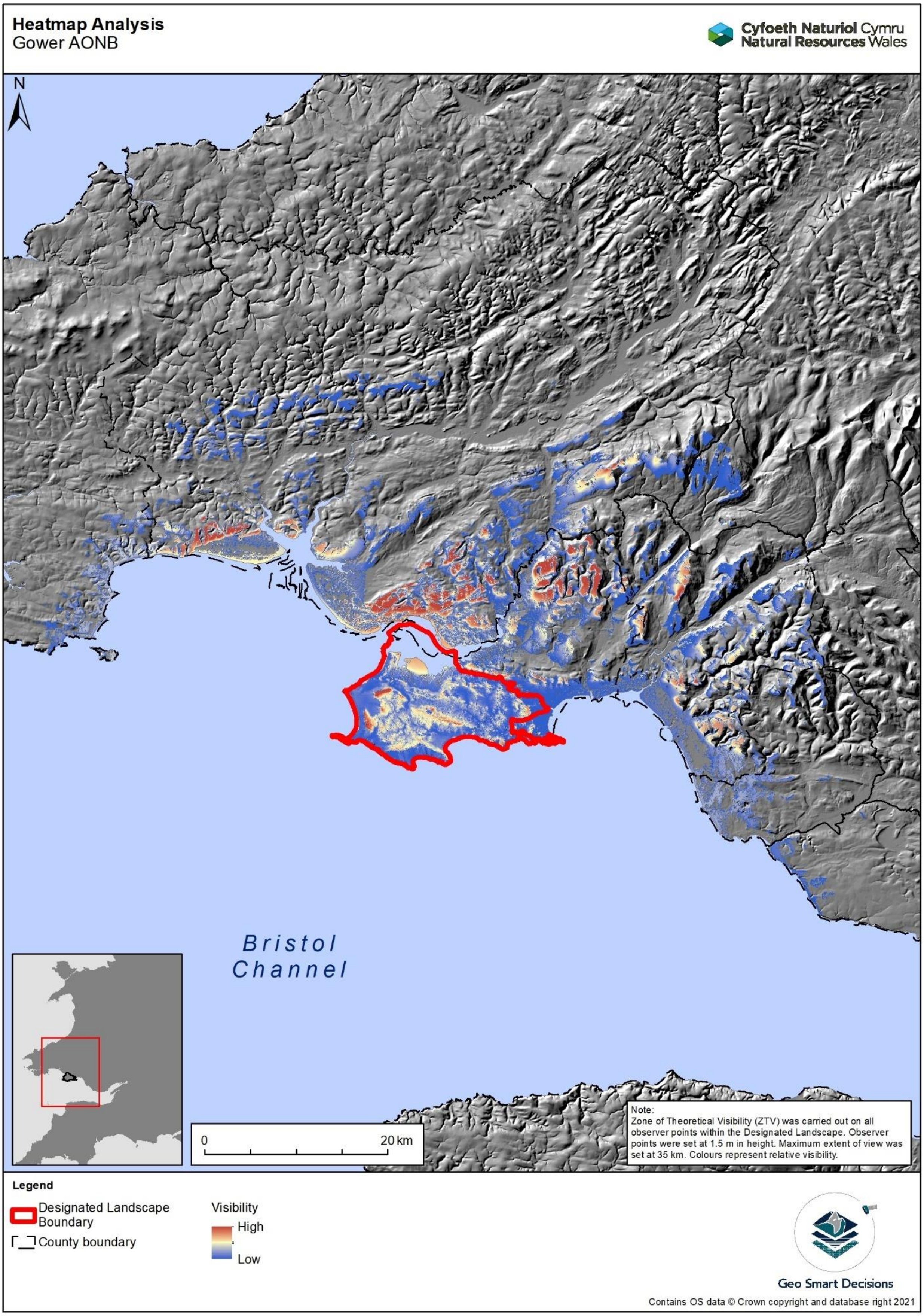

Height Object Becomes Visible (HOBV)
Wye Valley AONB with Pre-assessed Areas for Wind Energy layer (PAWE)
Cyfoeth Naturiol Cymru
Natural Resources Wales
0
20 km
Note:
Zone of Theoretical Visibility (ZTV) was carried out on all observer points within the Designated Landscape. Observer points were set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent heights that a vertical object would need to be to become visible at one of the observer points. PARE layer sourced from Lle Portal March 2021.
Legend
Observer point
County boundary
Designated Landscape Boundary
PAWE
Visible
HOBV (m)
< 25
26 - 49
50 - 79
80 - 108
109 - 145
146 - 175
176 - 225
226 - 350
350+
Geo Smart Decisions
Contains OS data © Crown copyright and database right 2021

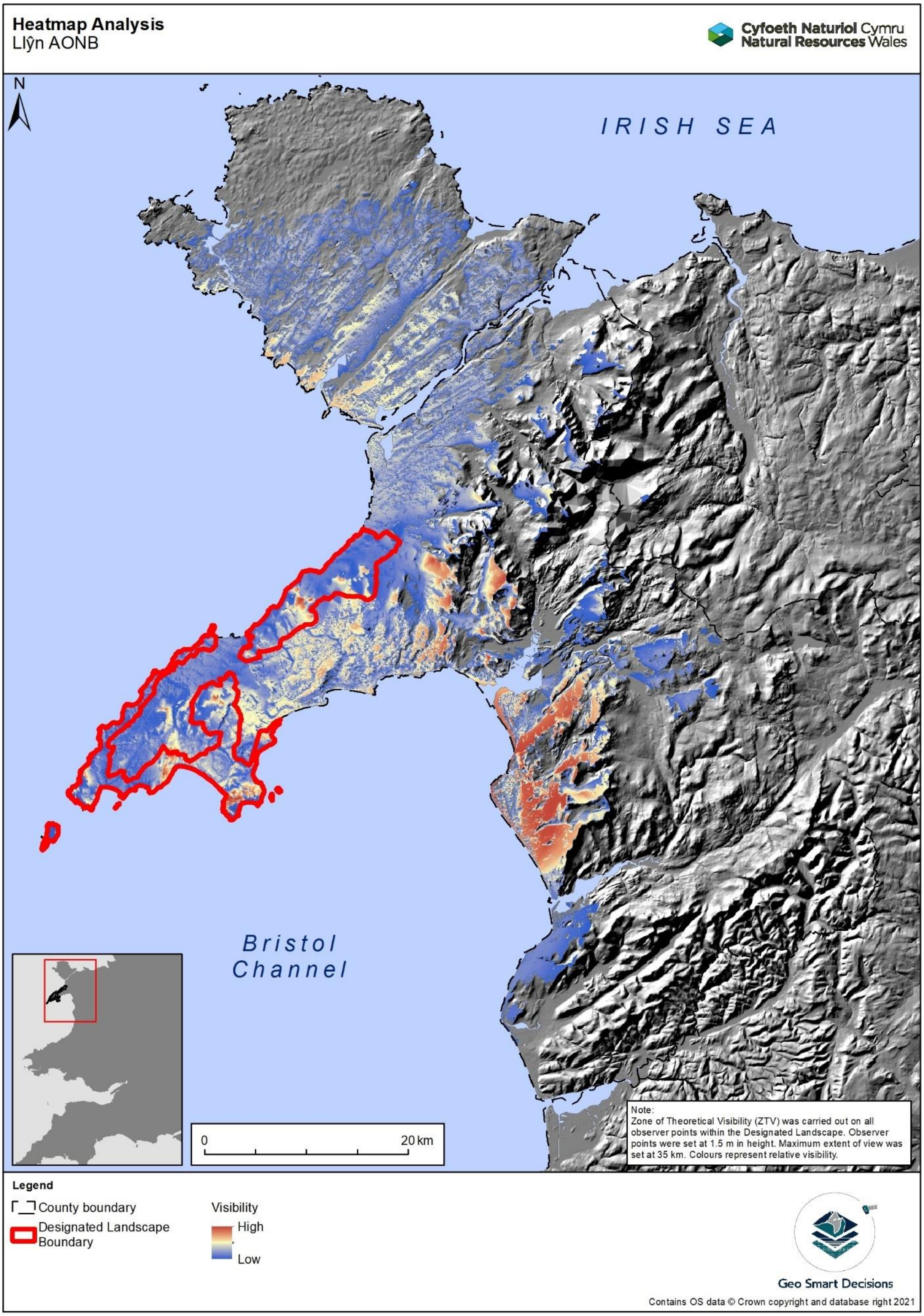
Appendix 3: Heatmap

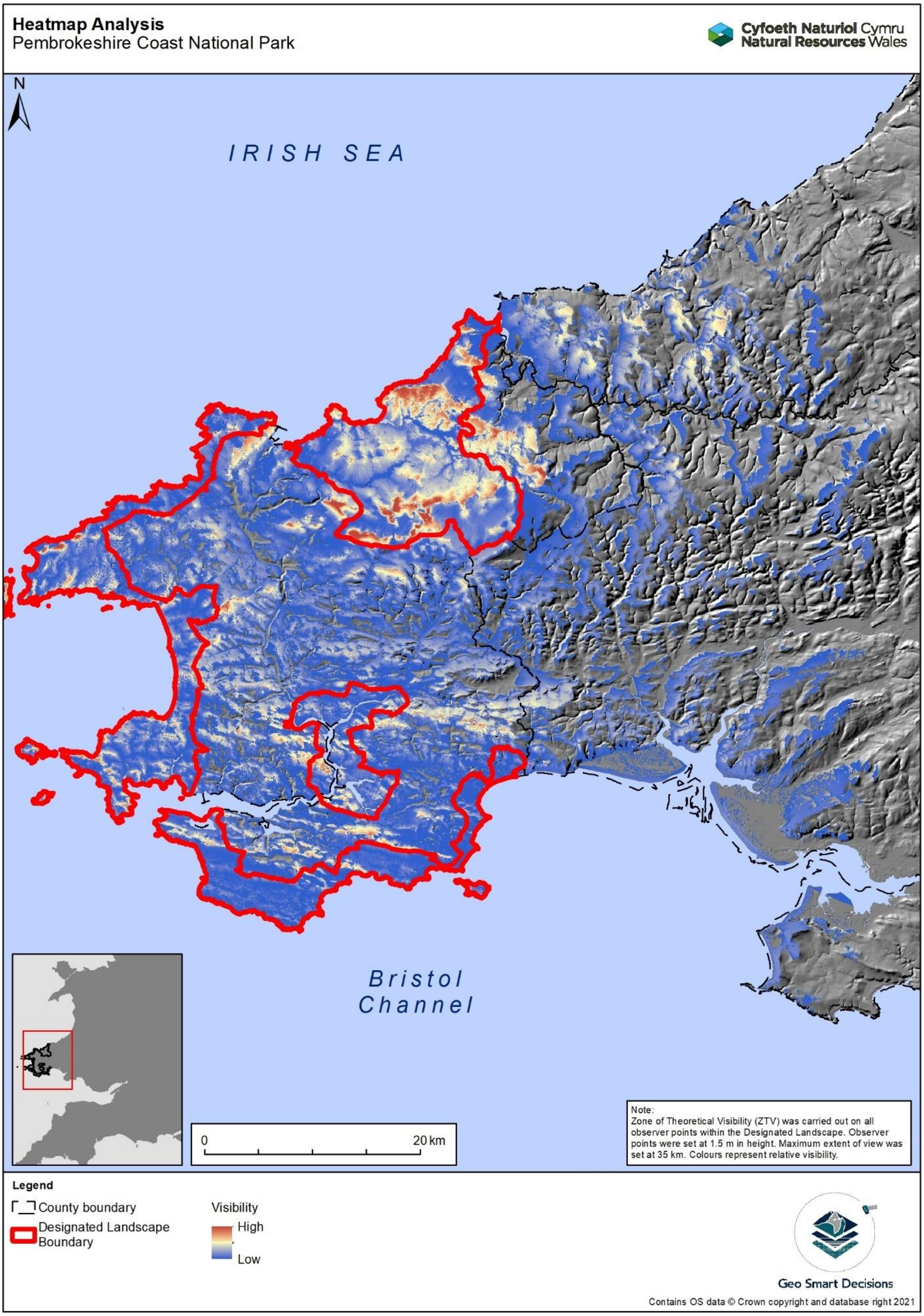


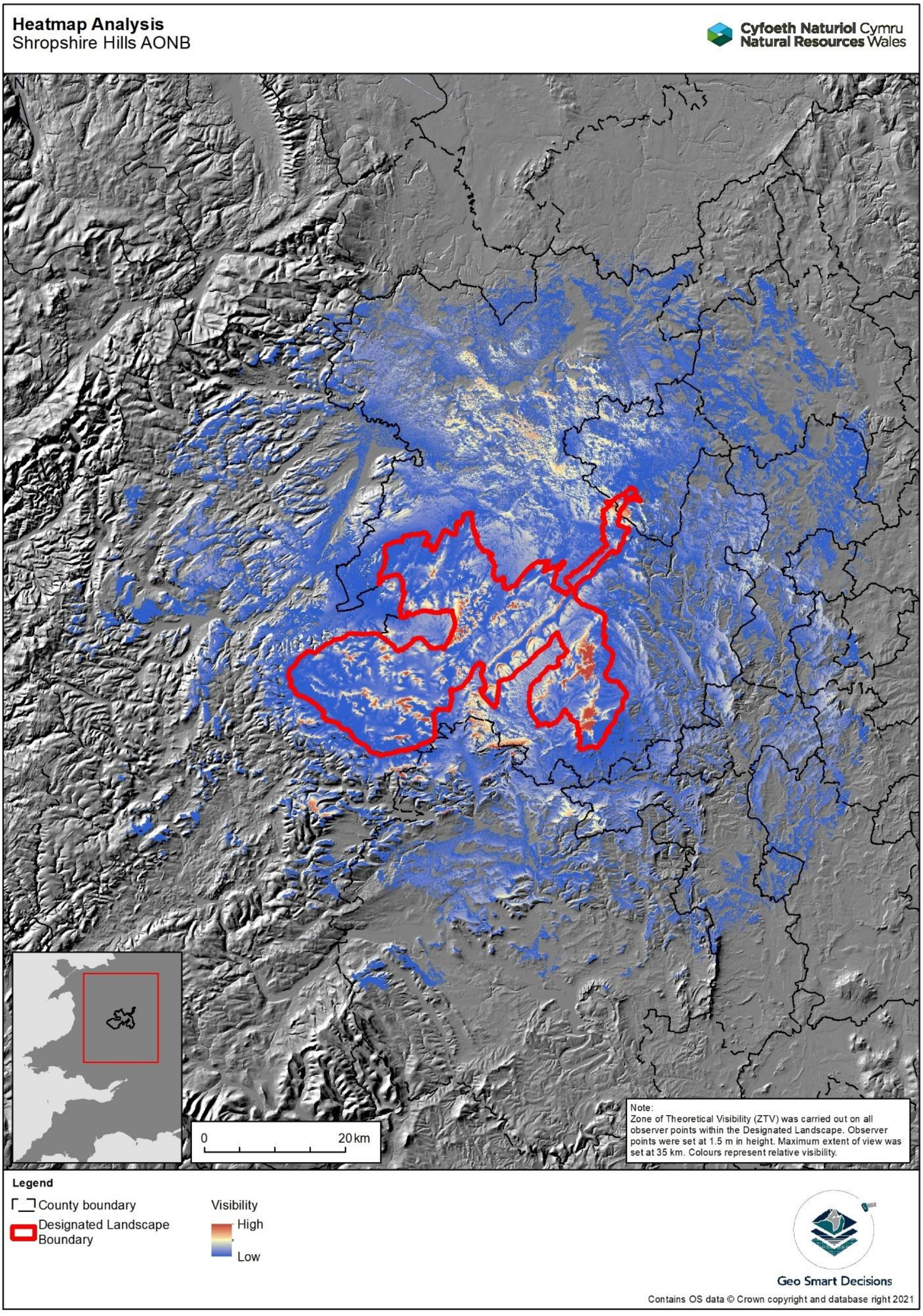

Heatmap Analysis
Brecon Beacons National Park
Cyfoeth Naturiol Cymru
Natural Resources Wales
N
Cardigan Bay
Bristol Channel
0
20 km
Note:
Zone of Theoretical Visibility (ZTV) was carried out on all observer points within the Designated Landscape. Observer points were set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent relative visibility.
Legend
County boundary
Designated Landscape Boundary
Visibility
High
Low
Geo Smart Decisions
Contains OS data © Crown copyright and database right 2021


Heatmap Analysis
Clwydian Range and Dee Valley AONB
Cyfoeth Naturiol Cymru
Natural Resources Wales
N
IRISH SEA
0
20 km
Note:
Zone of Theoretical Visibility (ZTV) was carried out on all observer points within the Designated Landscape. Observer points were set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent relative visibility.
Legend
County boundary
Designated Landscape Boundary
Visibility
High
Low
Geo Smart Decisions
Contains OS data © Crown copyright and database right 2021


Heatmap Analysis
Gower AONB
Cyfoeth Naturiol Cymru
Natural Resources Wales
N
Bristol Channel
0
20 km
Note:
Zone of Theoretical Visibility (ZTV) was carried out on all observer points within the Designated Landscape. Observer points were set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent relative visibility.
Legend
Designated Landscape Boundary
County boundary
Visibility
High
Low
Geo Smart Decisions
Contains OS data © Crown copyright and database right 2021

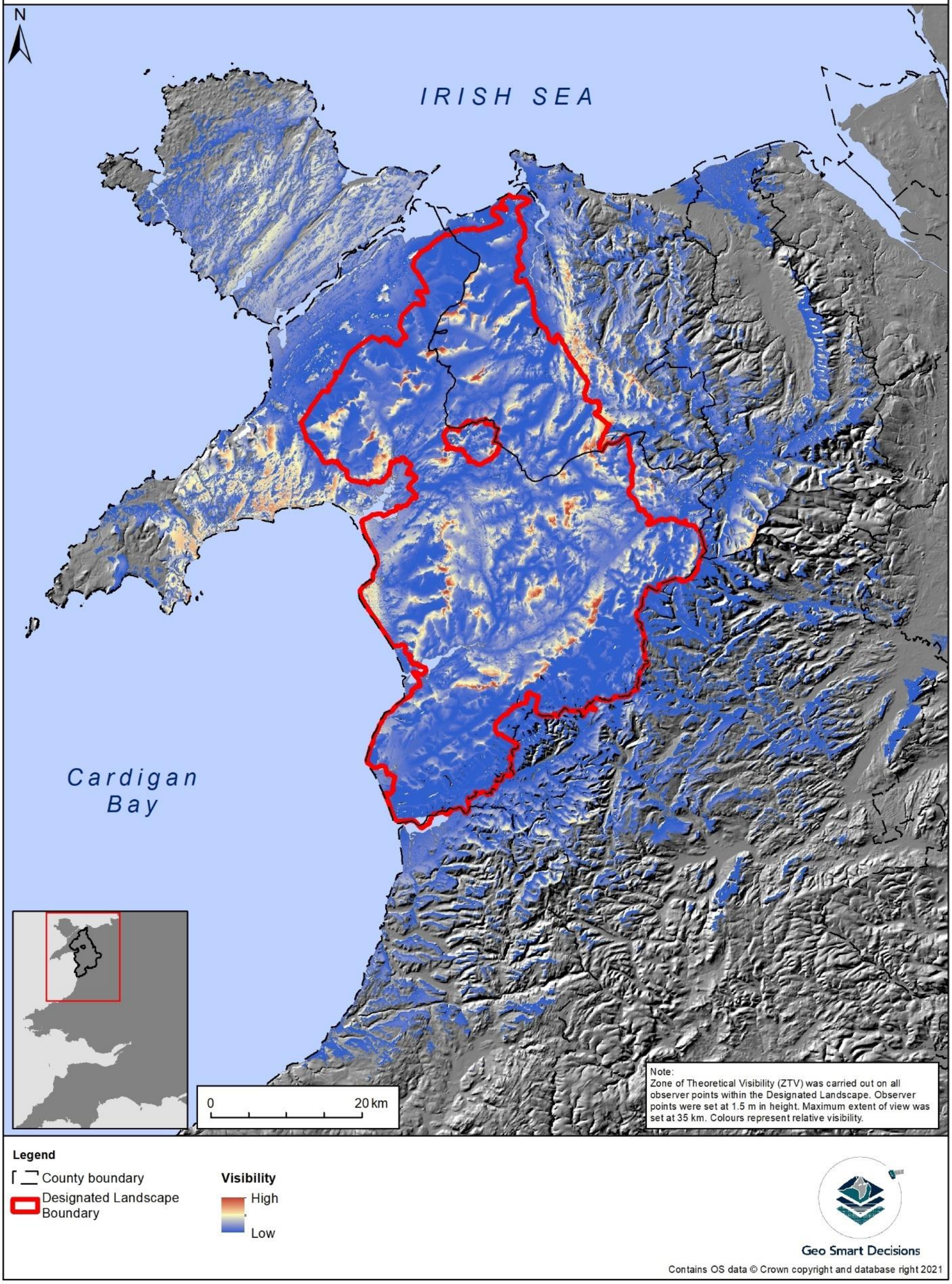

Heatmap Analysis
Llŷn AONB
Cyfoeth Naturiol Cymru
Natural Resources Wales
N
IRISH SEA
Bristol
Channel
0
20 km
Note:
Zone of Theoretical Visibility (ZTV) was carried out on all observer points within the Designated Landscape. Observer points were set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent relative visibility.
Legend
County boundary
Designated Landscape Boundary
Visibility
High
Low
Geo Smart Decisions
Contains OS data © Crown copyright and database right 2021

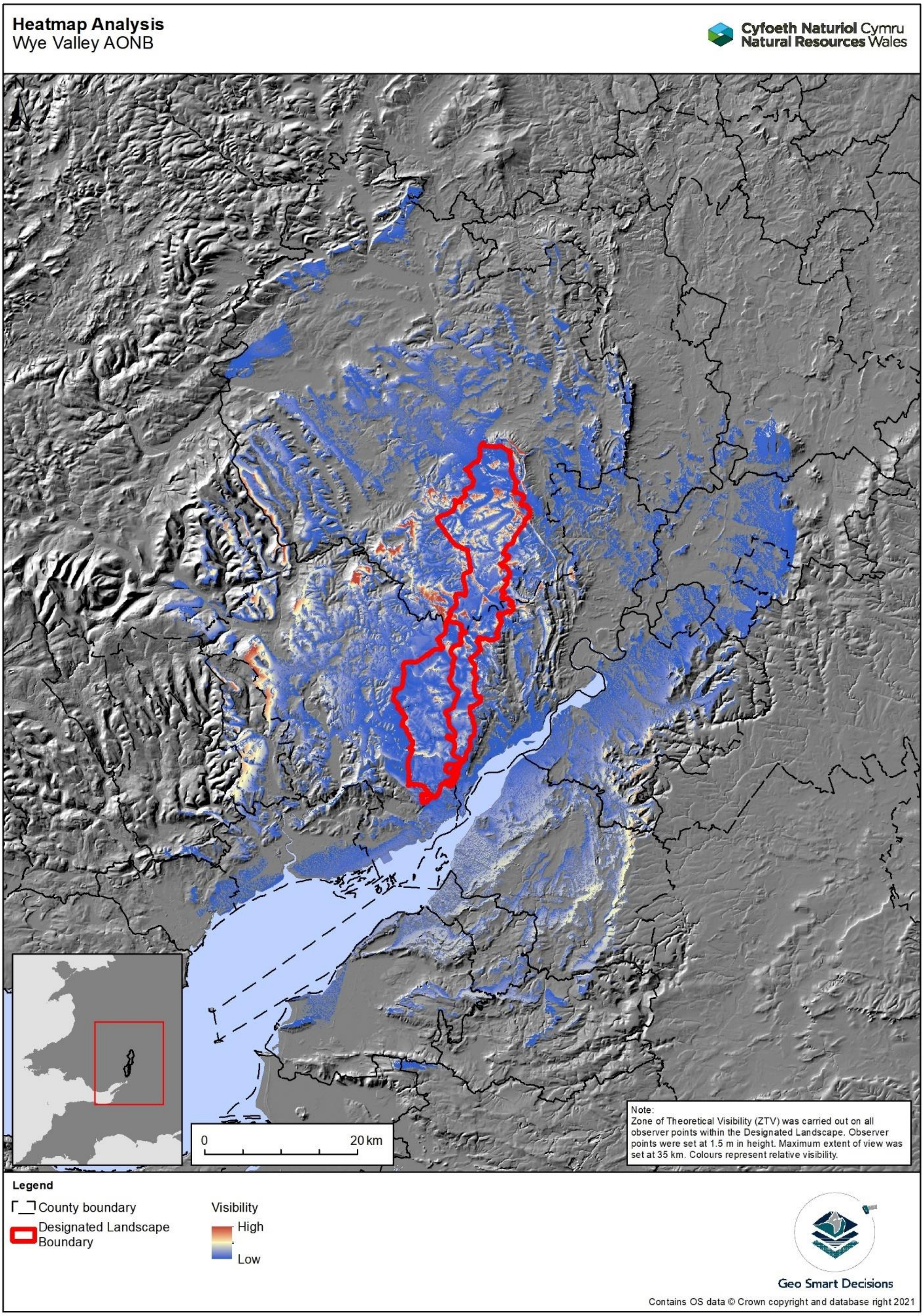

Heatmap Analysis
Pembrokeshire Coast National Park
Cyfoeth Naturiol Cymru
Natural Resources Wales
N
IRISH SEA
Bristol
Channel
0
20 km
Note:
Zone of Theoretical Visibility (ZTV) was carried out on all observer points within the Designated Landscape. Observer points were set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent relative visibility.
Legend
County boundary
Designated Landscape Boundary
Visibility
High
Low
Geo Smart Decisions
Contains OS data © Crown copyright and database right 2021


Heatmap Analysis
Shropshire Hills AONB
Cyfoeth Naturiol Cymru
Natural Resources Wales
N
0
20 km
Note:
Zone of Theoretical Visibility (ZTV) was carried out on all observer points within the Designated Landscape. Observer points were set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent relative visibility.
Legend
County boundary
Designated Landscape Boundary
Visibility
High
Low
Geo Smart Decisions
Contains OS data © Crown copyright and database right 2021

Heatmap Analysis
Snowdonia National Park

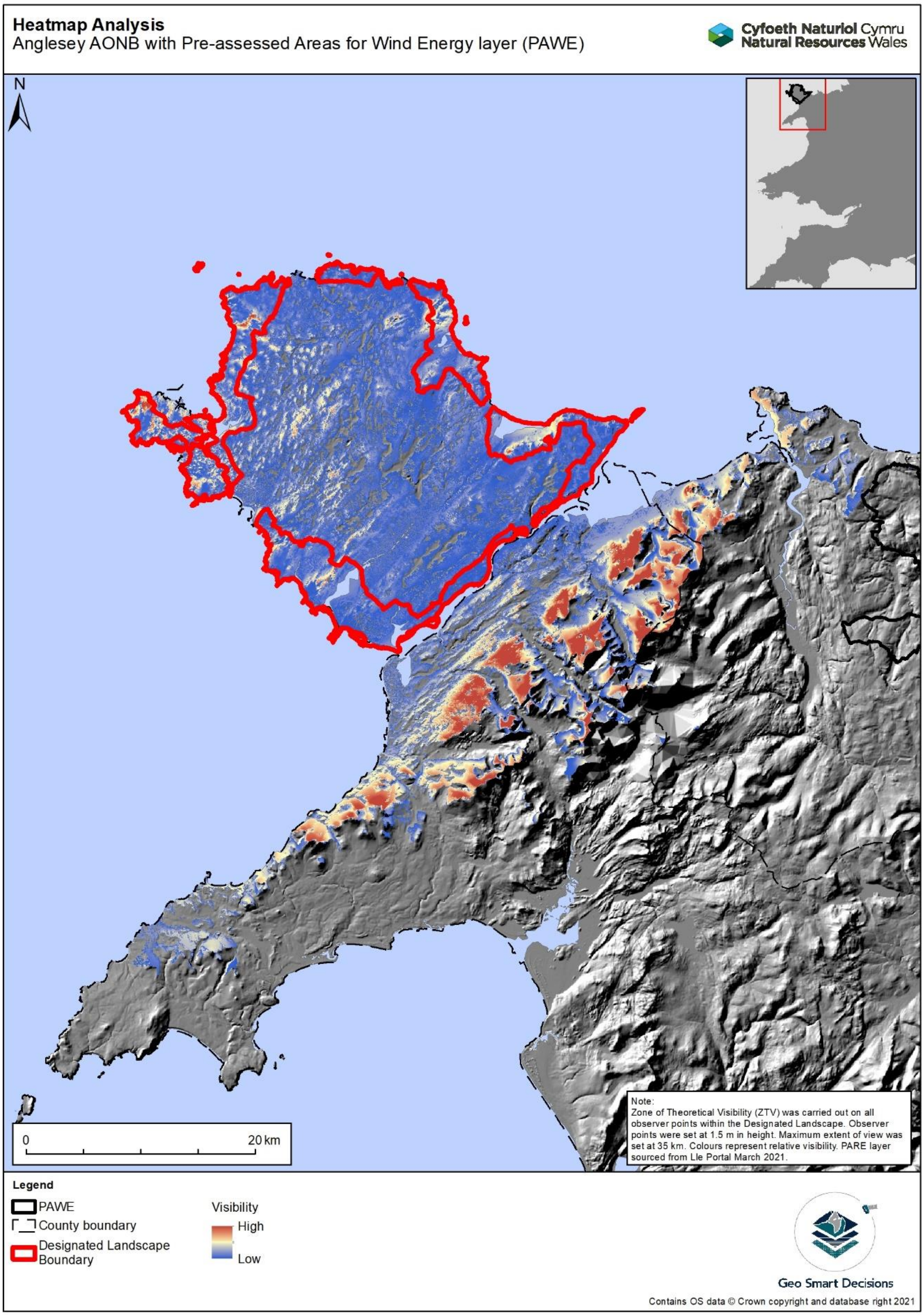
Cyfoeth Naturiol Cymru
Natural Resources Wales

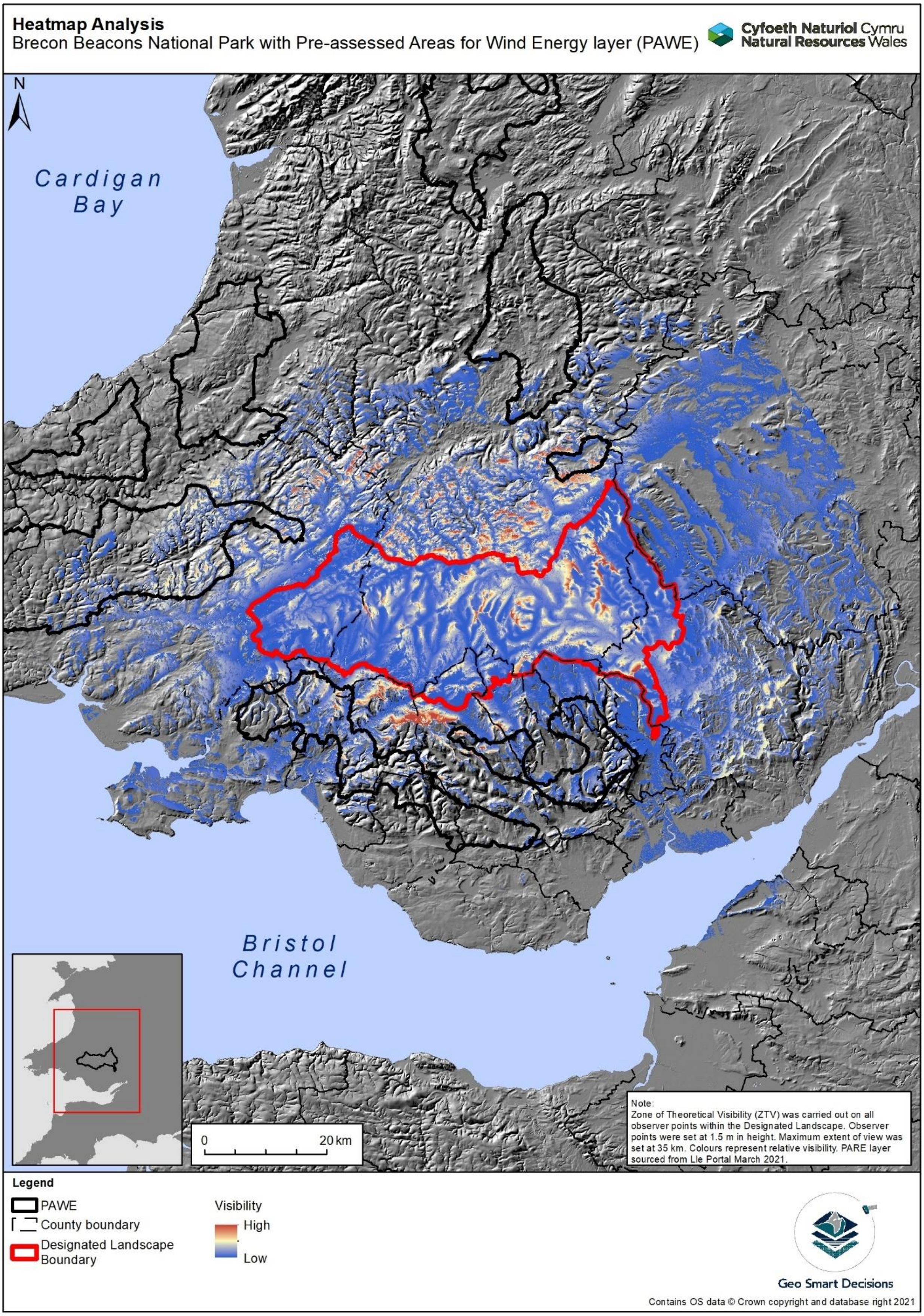




Heatmap Analysis
Wye Valley AONB
Cyfoeth Naturiol Cymru
Natural Resources Wales
0
20 km
Note:
Zone of Theoretical Visibility (ZTV) was carried out on all observer points within the Designated Landscape. Observer points were set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent relative visibility.
Legend
County boundary
Designated Landscape Boundary
Visibility
High
Low
Geo Smart Decisions
Contains OS data © Crown copyright and database right 2021

Appendix 4: Heatmaps with PAWE layers

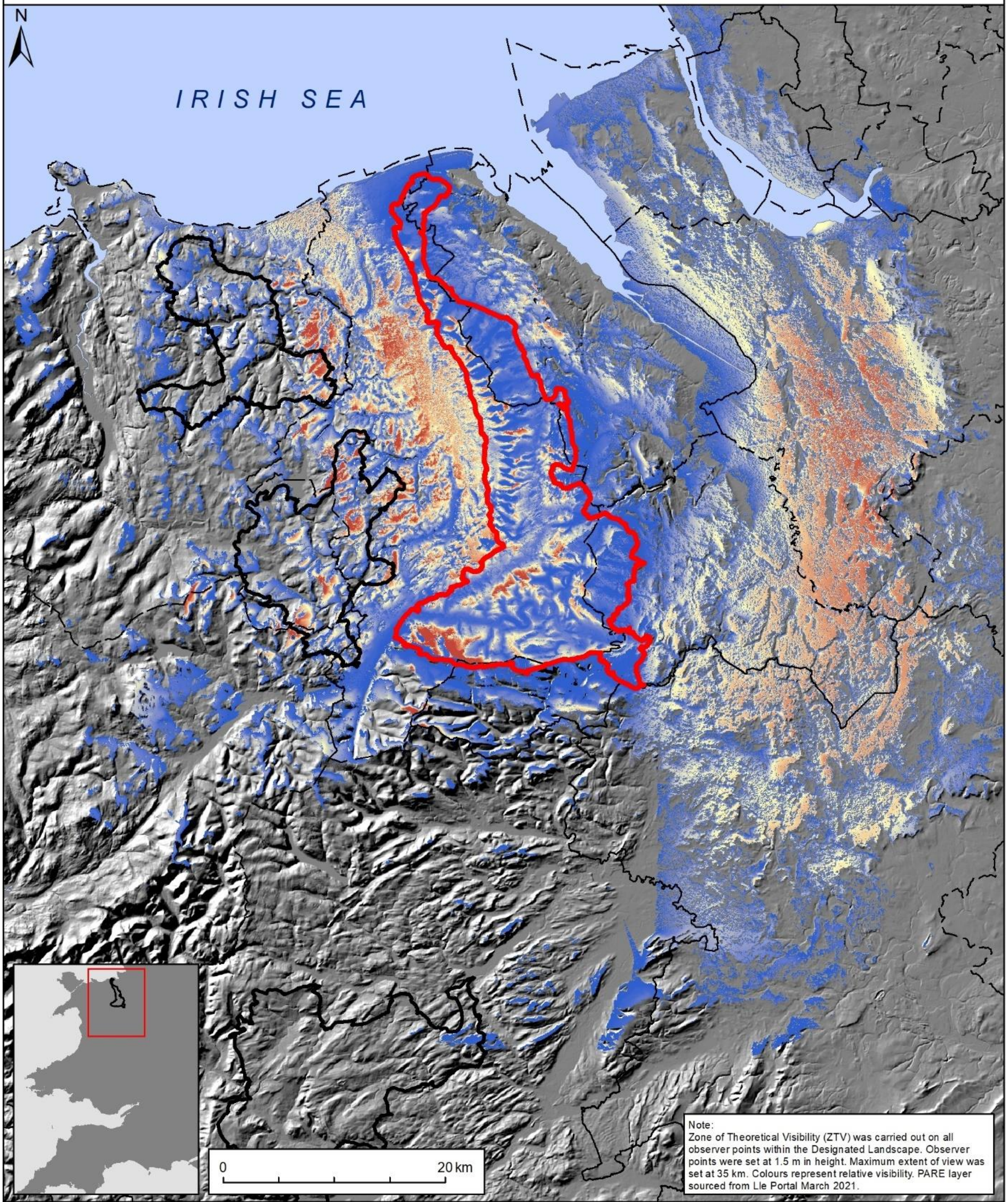



Heatmap Analysis
Brecon Beacons National Park with Pre-assessed Areas for Wind Energy layer (PAWE)
Cyfoeth Naturiol Cymru
Natural Resources Wales
N
Cardigan Bay
Bristol Channel
0
20 km
Note:
Zone of Theoretical Visibility (ZTV) was carried out on all observer points within the Designated Landscape. Observer points were set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent relative visibility. PARE layer sourced from Lle Portal March 2021.
Legend
PAWE
County boundary
Designated Landscape Boundary
Visibility
High
Low
Geo Smart Decisions
Contains OS data © Crown copyright and database right 2021

Heatmap Analysis

Clwydian Range and Dee Valley AONB with Pre-assessed Areas for Wind Energy layer (PAWE)

Cyfoeth Naturiol Cymru
Natural Resources Wales



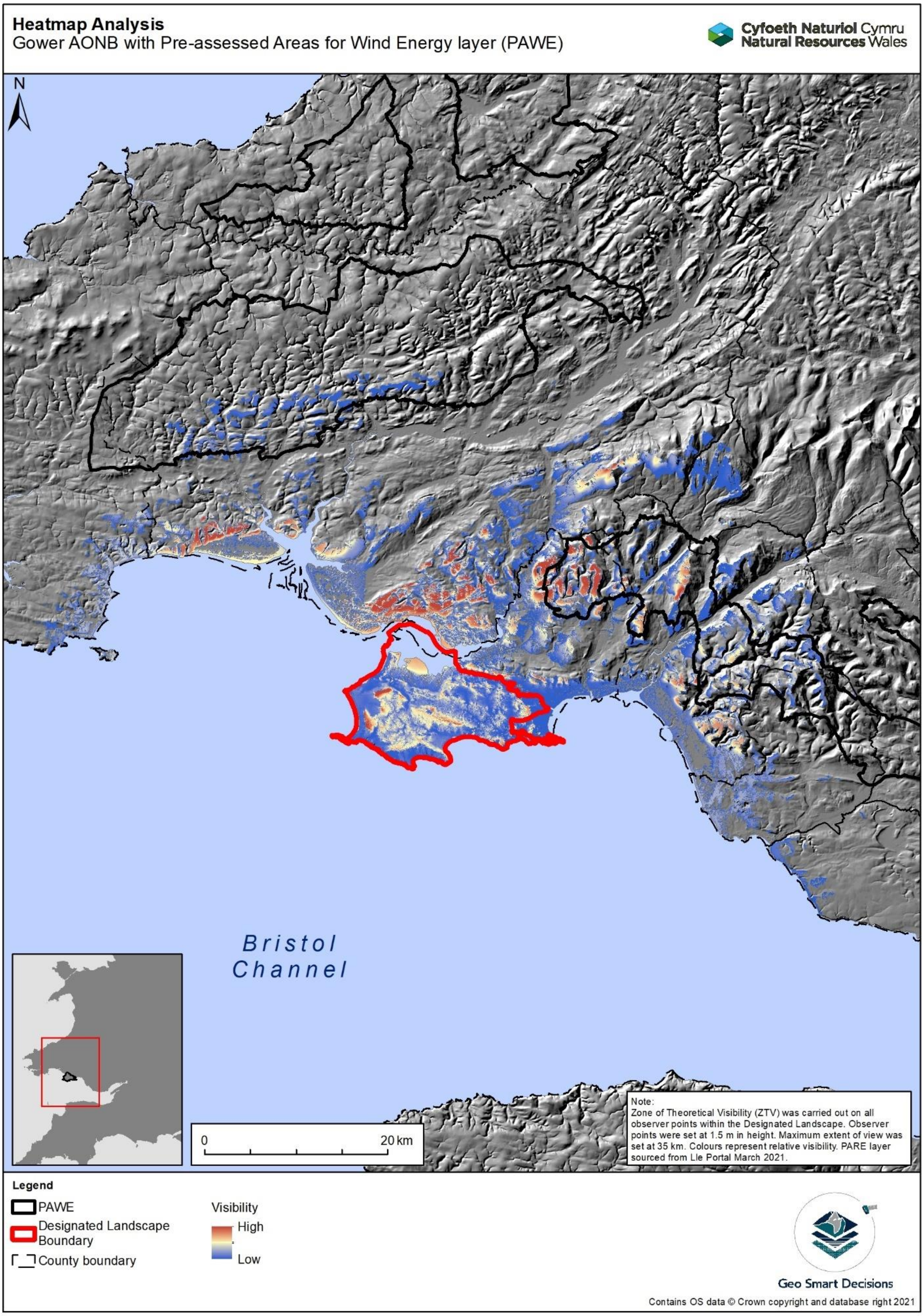
Legend

- PAWE
- County boundary
- Designated Landscape Boundary

Visibility

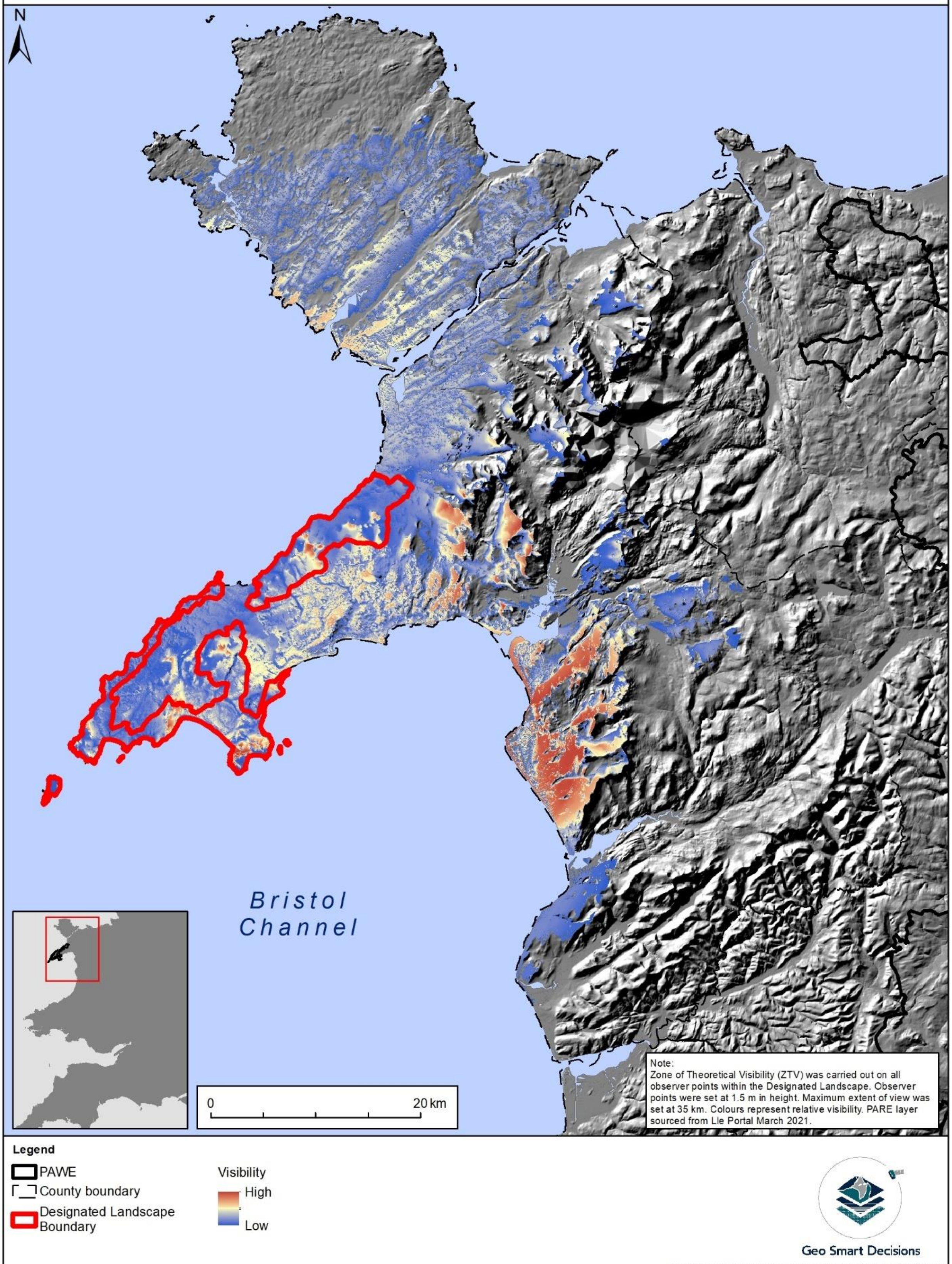
- High
- Low

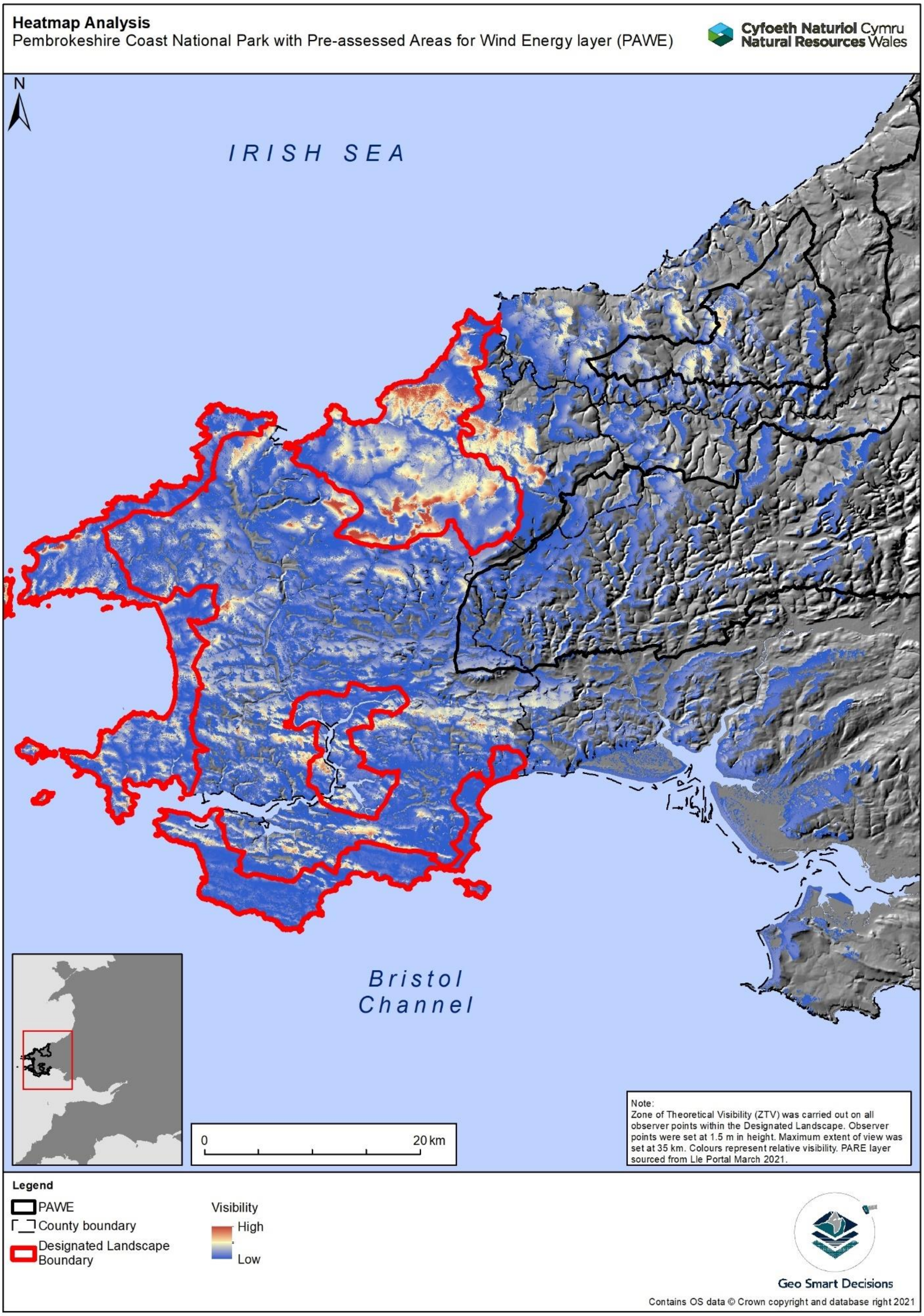
Geo Smart Decisions


Heatmap Analysis
Gower AONB with Pre-assessed Areas for Wind Energy layer (PAWE)
Cyfoeth Naturiol Cymru
Natural Resources Wales
N
Bristol Channel
0
20 km
Note:
Zone of Theoretical Visibility (ZTV) was carried out on all observer points within the Designated Landscape. Observer points were set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent relative visibility. PARE layer sourced from Lle Portal March 2021.
Legend
PAWE
Designated Landscape Boundary
County boundary
Visibility
High
Low
Geo Smart Decisions
Contains OS data © Crown copyright and database right 2021

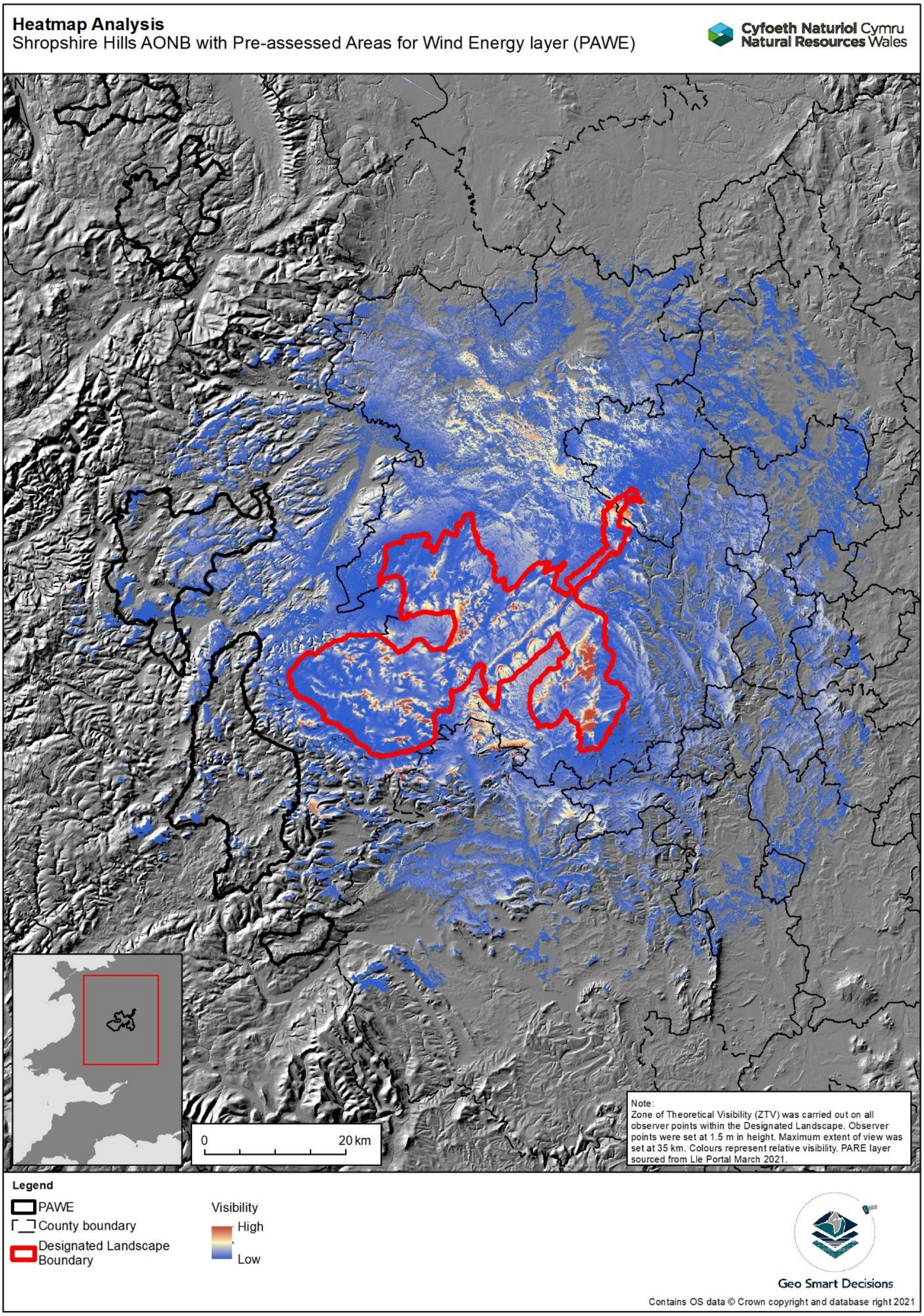
Heatmap Analysis
Llŷn AONB with Pre-assessed Areas for Wind Energy layer (PAWE)

Cyfoeth Naturiol Cymru
Natural Resources Wales





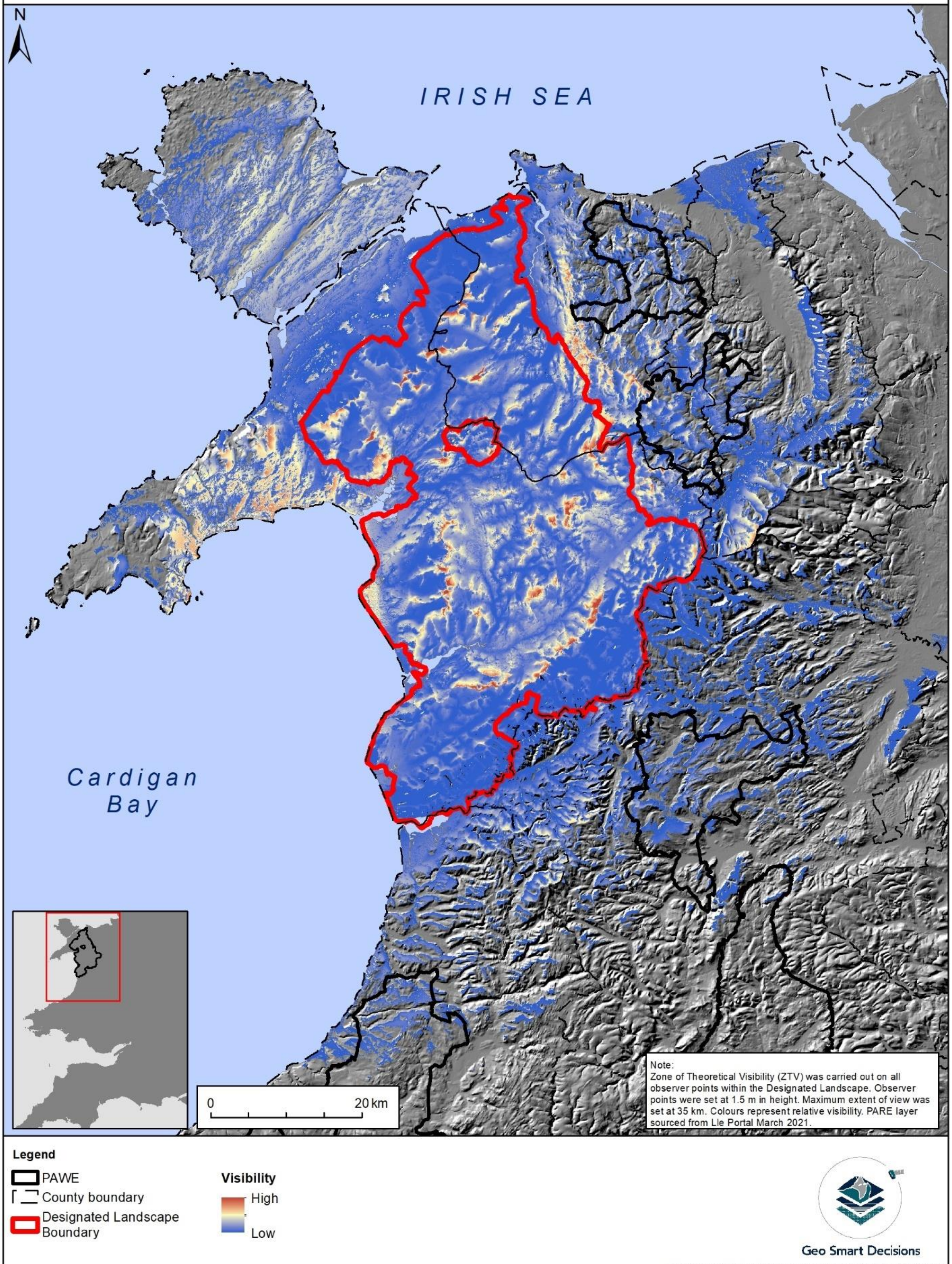
Heatmap Analysis
Pembrokeshire Coast National Park with Pre-assessed Areas for Wind Energy layer (PAWE)
Cyfoeth Naturiol Cymru
Natural Resources Wales
N
IRISH SEA
Bristol Channel
0
20 km
Note:
Zone of Theoretical Visibility (ZTV) was carried out on all observer points within the Designated Landscape. Observer points were set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent relative visibility. PARE layer sourced from Lle Portal March 2021.
Legend
PAWE
County boundary
Designated Landscape Boundary
Visibility
High
Low
Geo Smart Decisions
Contains OS data © Crown copyright and database right 2021


Heatmap Analysis
Shropshire Hills AONB with Pre-assessed Areas for Wind Energy layer (PAWE)
Cyfoeth Naturiol Cymru
Natural Resources Wales
N
0
20 km
Note:
Zone of Theoretical Visibility (ZTV) was carried out on all observer points within the Designated Landscape. Observer points were set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent relative visibility. PARE layer sourced from Lle Portal March 2021.
Legend
PAWE
County boundary
Designated Landscape Boundary
Visibility
High
Low
Geo Smart Decisions
Contains OS data © Crown copyright and database right 2021

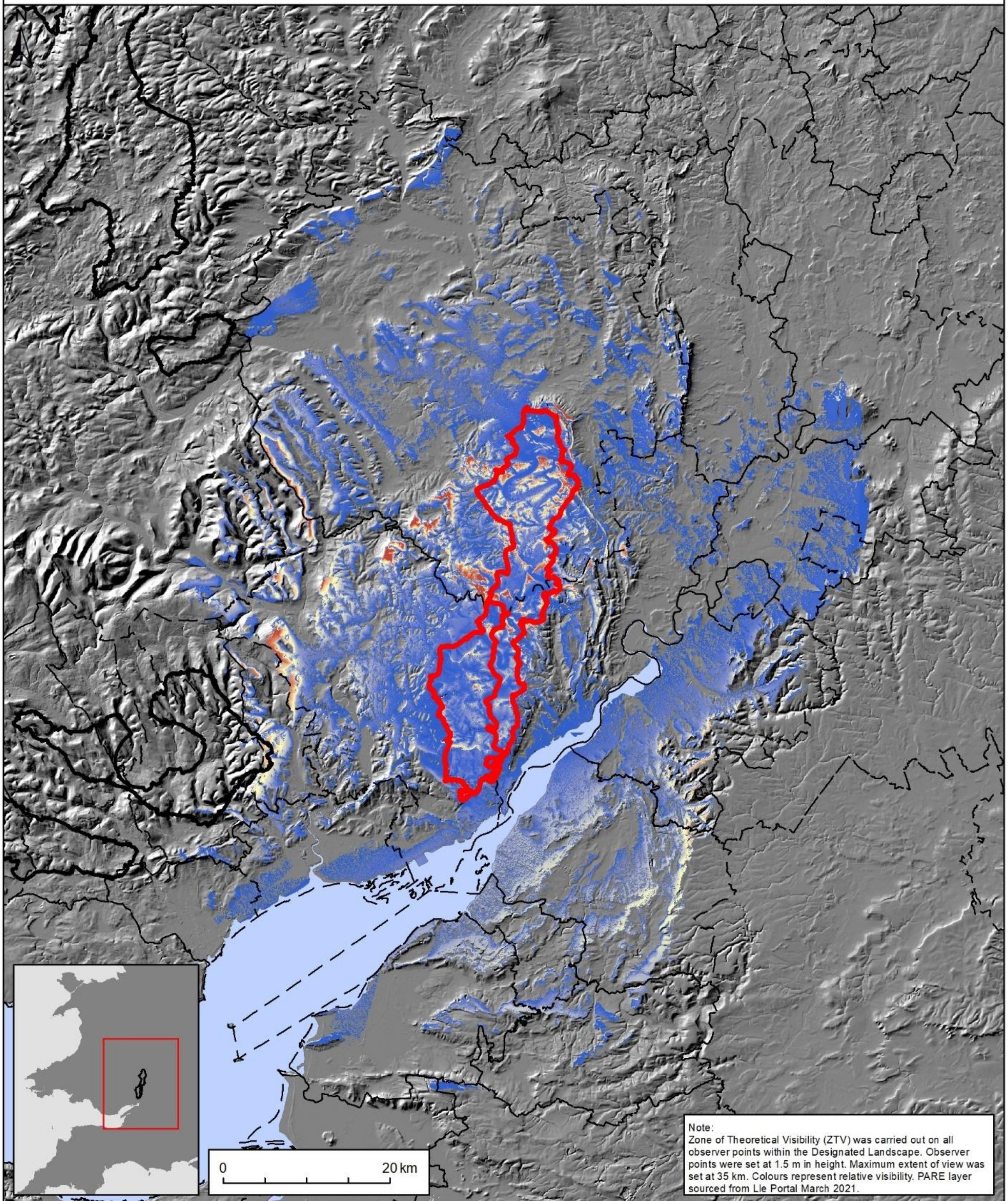
Heatmap Analysis

Snowdonia National Park with Pre-assessed Areas for Wind Energy layer (PAWE)

Cyfoeth Naturiol Cymru
Natural Resources Wales



Heatmap Analysis
Wye Valley AONB with Pre-assessed Areas for Wind Energy layer (PAWE)



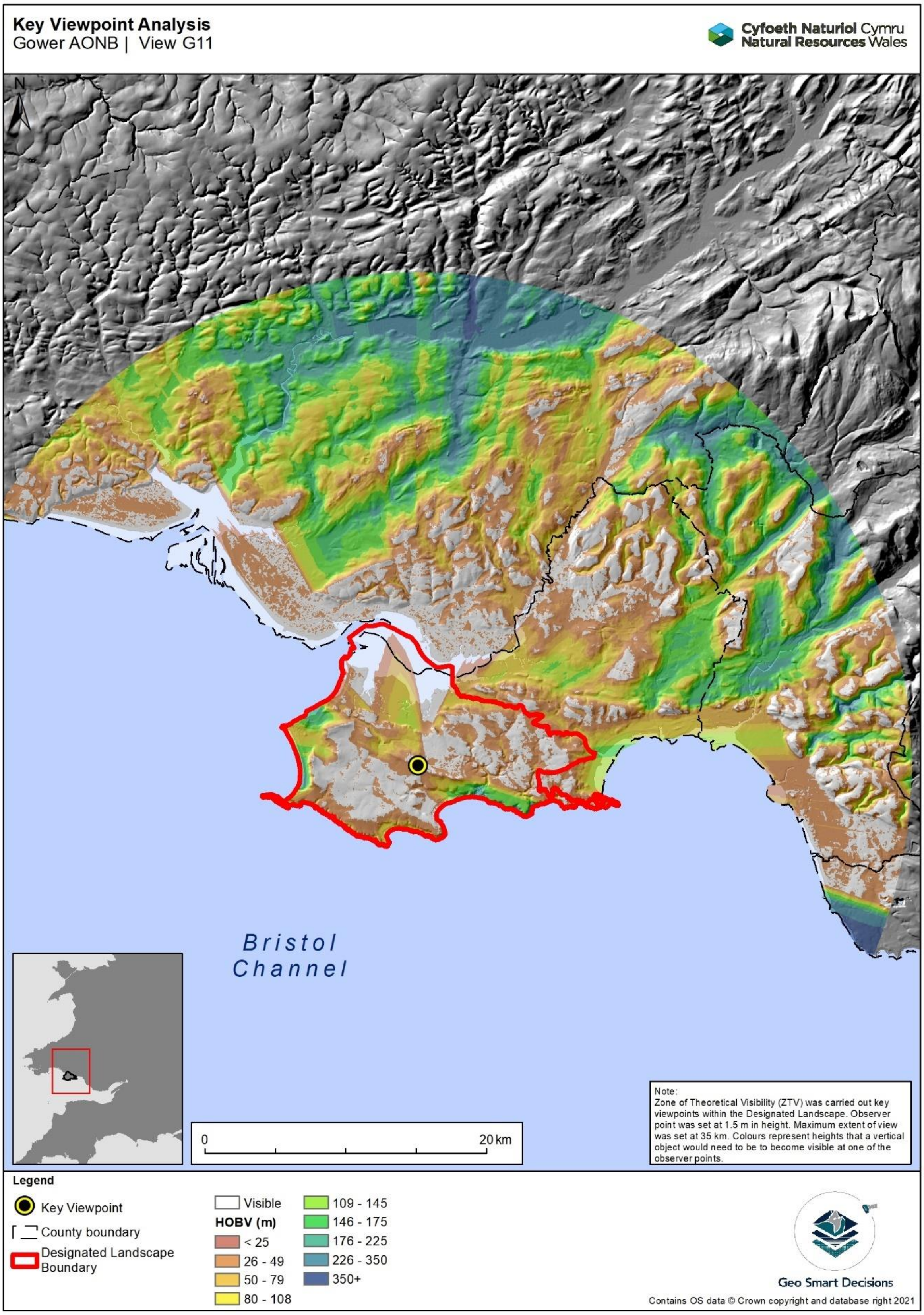
Legend

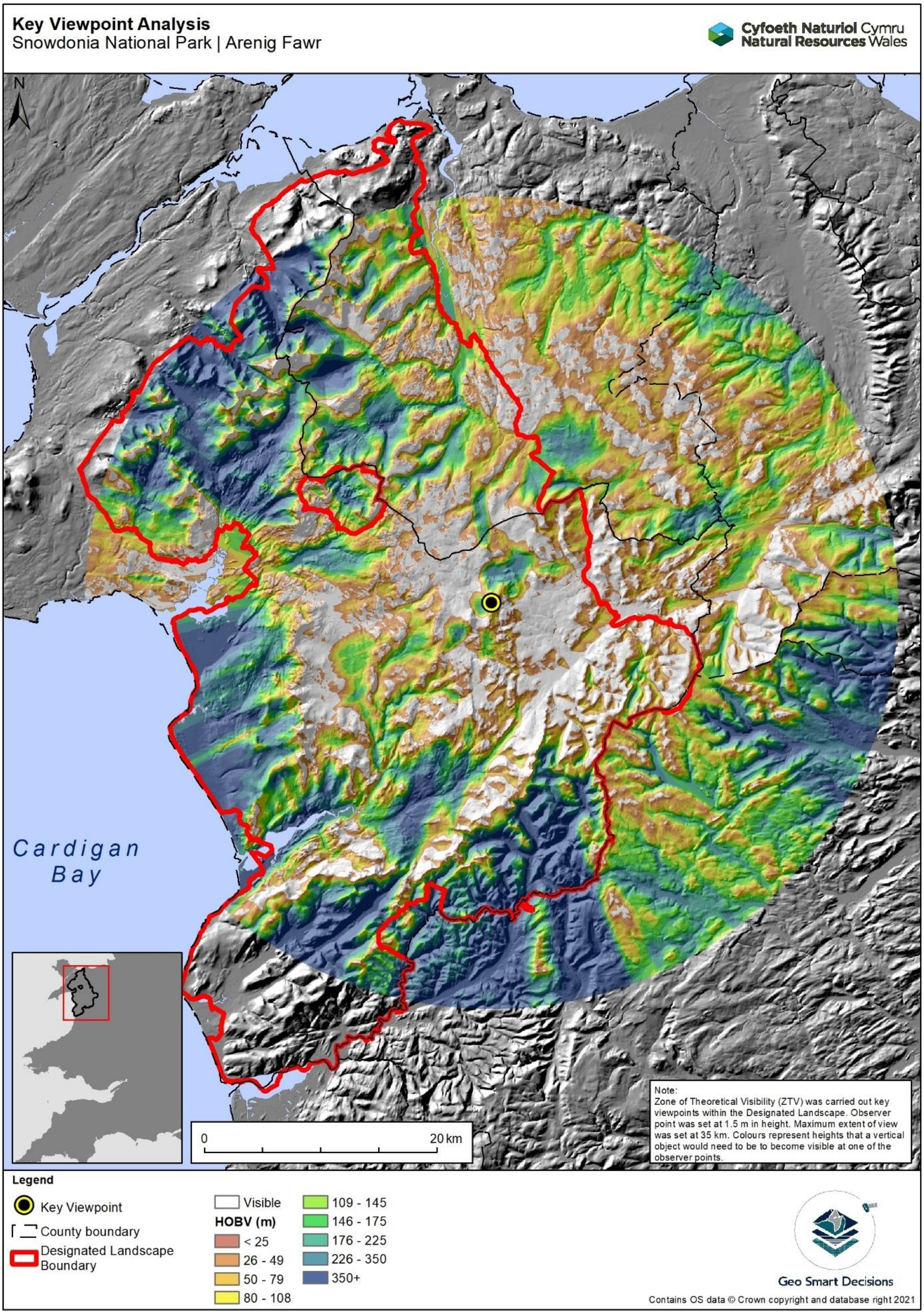
- PAWE
- County boundary
- Designated Landscape Boundary

Visibility
- High
- Low

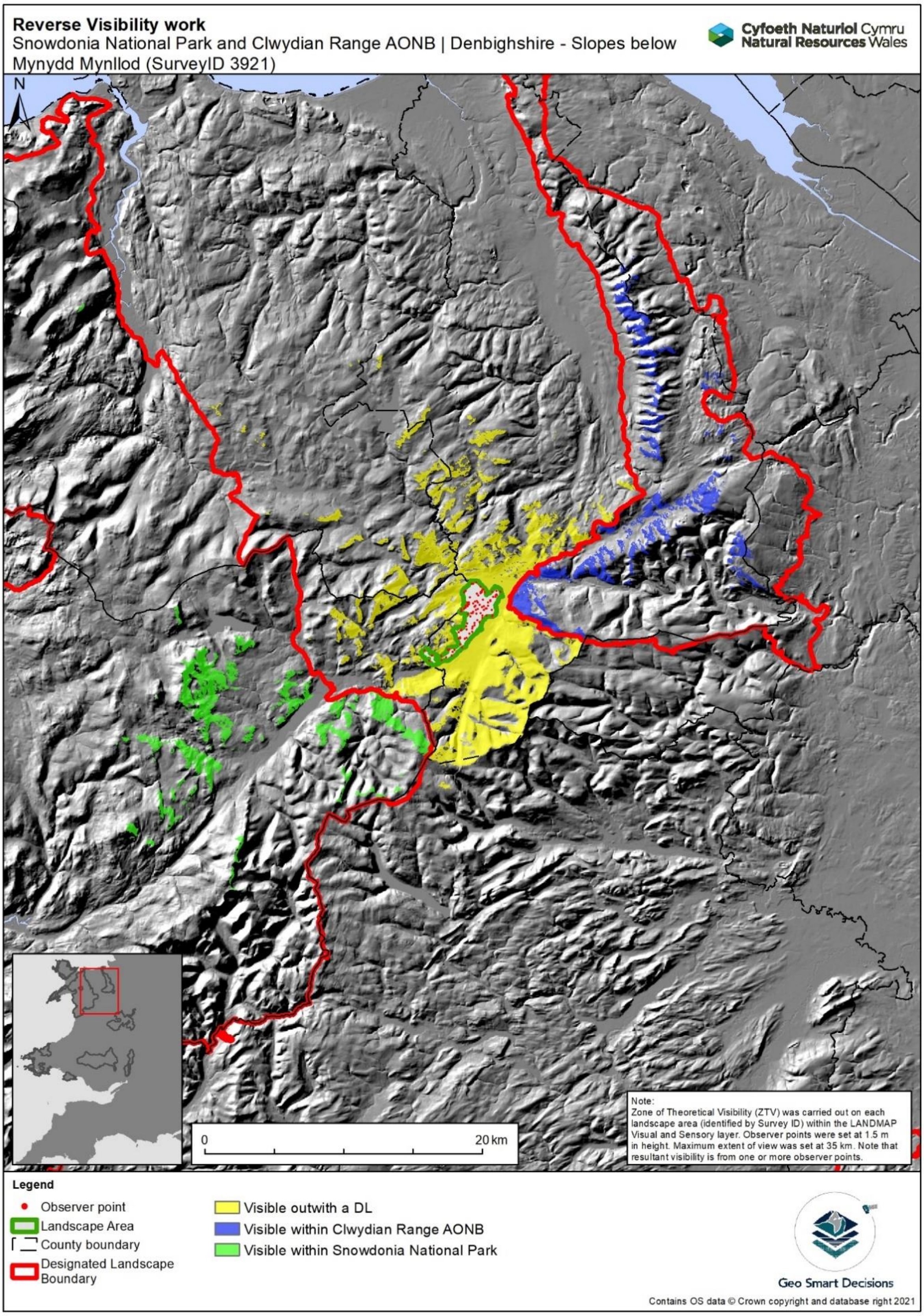
Geo Smart Decisions

Appendix 5: Key Viewpoints Map Examples



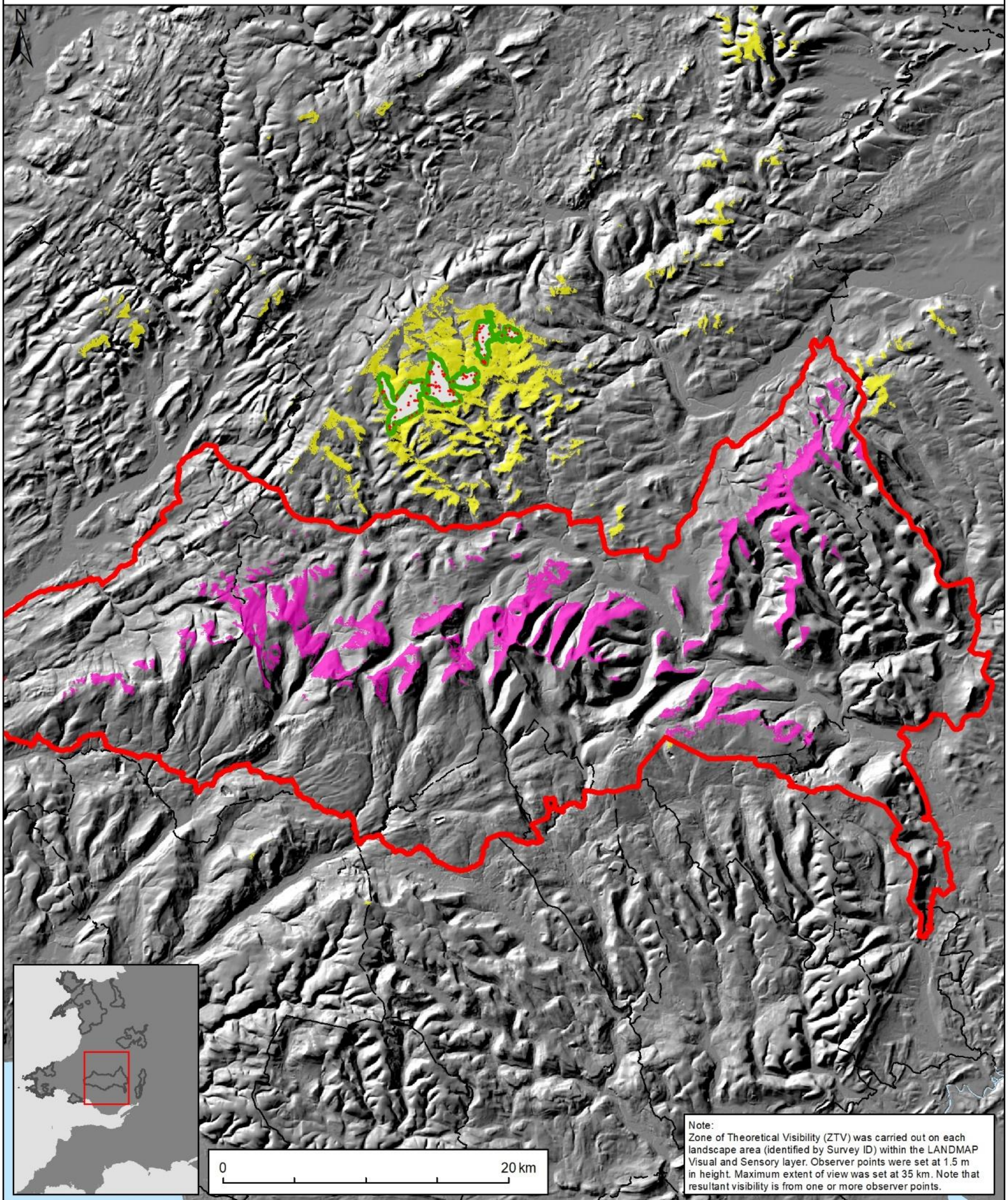

Key Viewpoint Analysis
Snowdonia National Park | Arenig Fawr
Cyfoeth Naturiol Cymru
Natural Resources Wales
N
Cardigan
Bay
0
20 km
Note:
Zone of Theoretical Visibility (ZTV) was carried out key viewpoints within the Designated Landscape. Observer point was set at 1.5 m in height. Maximum extent of view was set at 35 km. Colours represent heights that a vertical object would need to be to become visible at one of the observer points.
Legend
Key Viewpoint
County boundary
Designated Landscape Boundary
Visible
HOBV (m)
< 25
26 - 49
50 - 79
80 - 108
109 - 145
146 - 175
176 - 225
226 - 350
350+
Geo Smart Decisions
Contains OS data © Crown copyright and database right 2021

Appendix 6: Reverse Visibility Map Examples



Reverse-visibility work
Brecon Beacons National Park | Brecknockshire - SENTA Valley Heads (SurveyID109)

Cyfoeth Naturiol Cymru
Natural Resources Wales



Legend

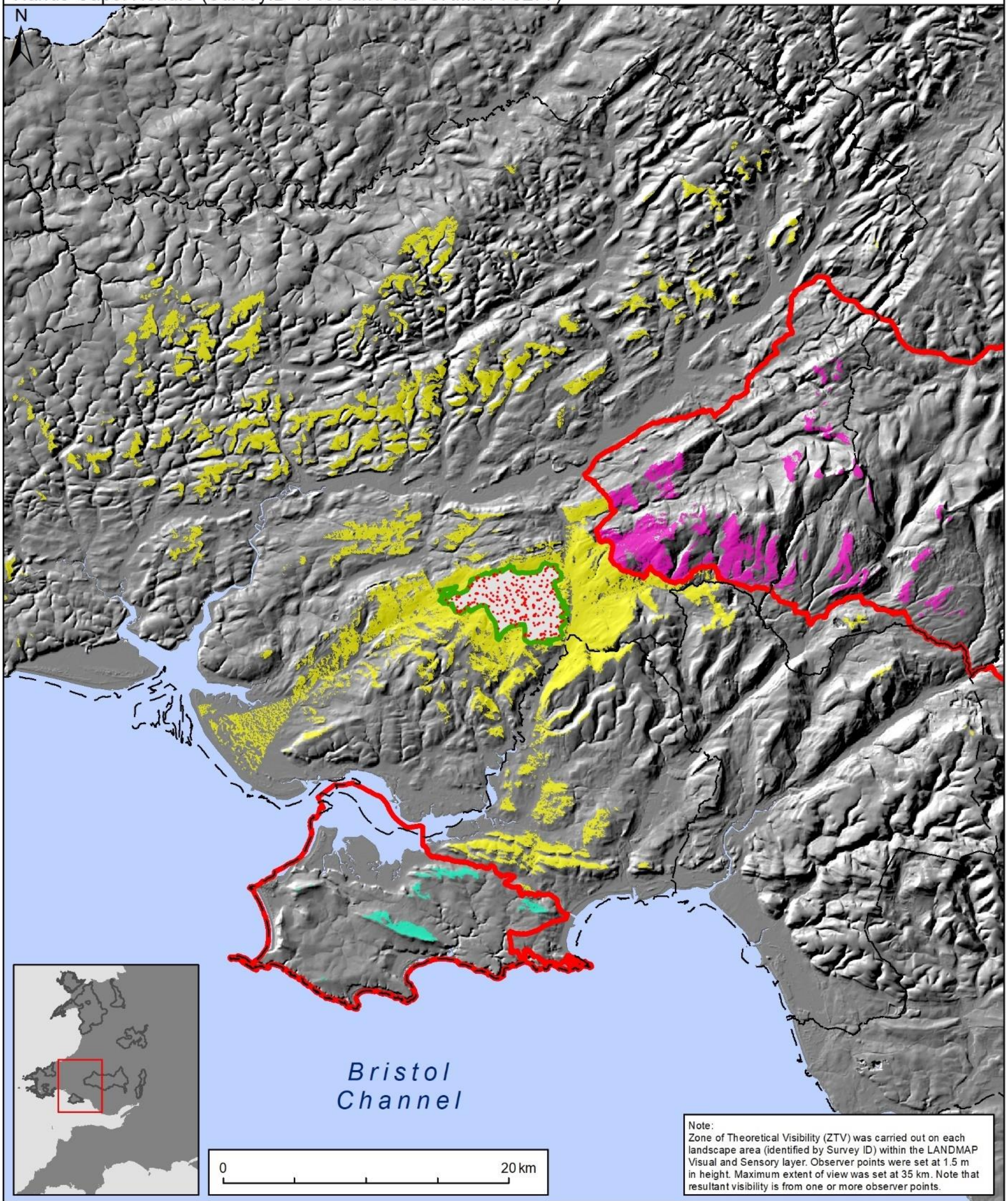
- Observer point
- Landscape Area
- County boundary
- Designated Landscape Boundary
- Visible outwith a DL
- Visible within Brecon Beacons National Park

Geo Smart Decisions

Reverse-visibility work

Gower AONB and Brecon Beacons National Park | Carmarthenshire - Cross Hands-Capel Hendre (SurveyID 11488 and UID CRMRTVS277)

Cyfoeth Naturiol Cymru
Natural Resources Wales



Legend

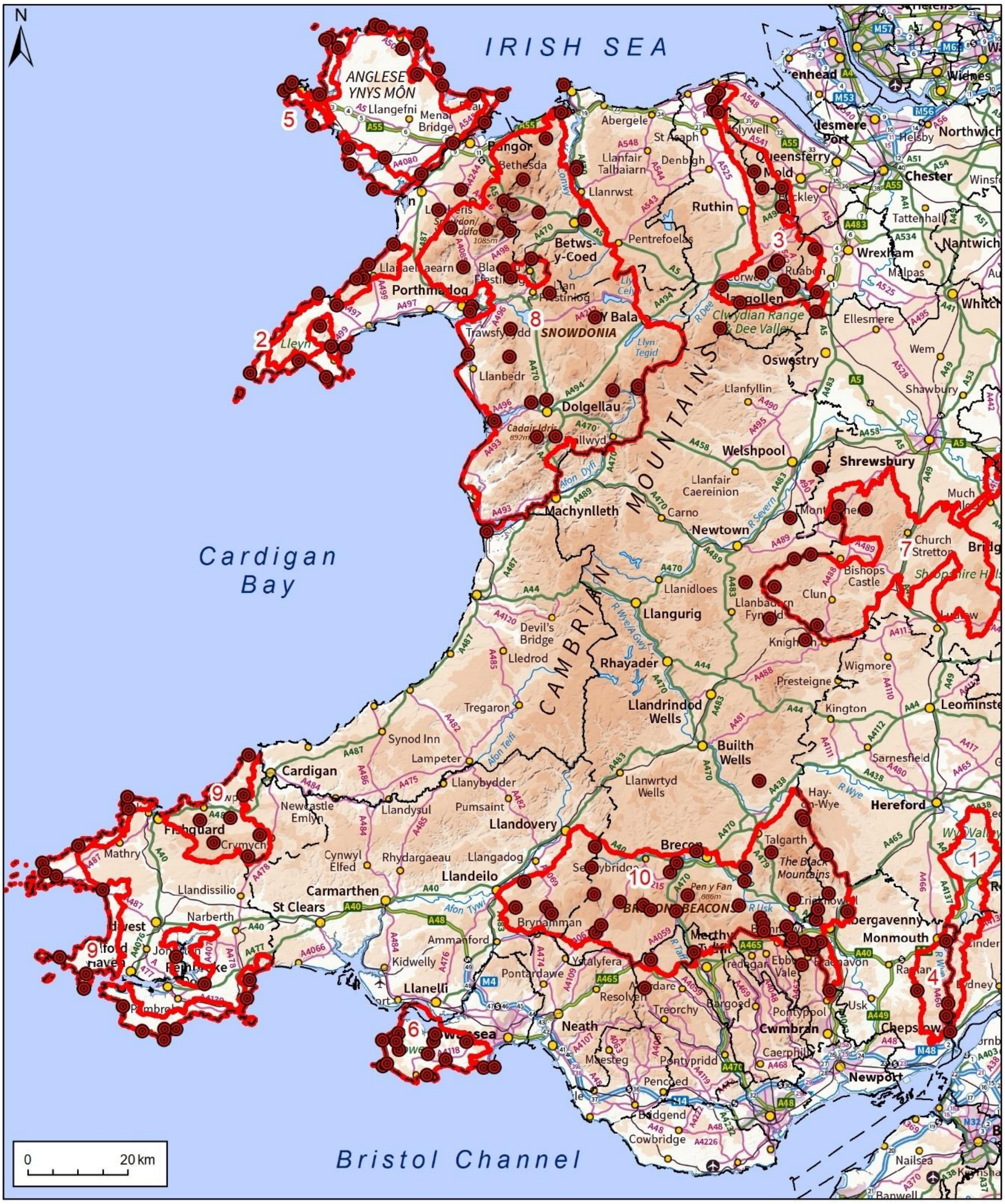
- Observer point
- Landscape Area
- County boundary
- Designated Landscape Boundary
- Visible outwith a DL
- Visible within Brecon Beacon National Park
- Visible within Gower Peninsula AONB

Geo Smart Decisions

Appendix 7: Key viewpoints used in analysis

Viewpoints used to create ZTV heatmaps and HOBV layers
Viewpoints and Designated Landscapes in Wales

Cyfoeth Naturiol Cymru
Natural Resources Wales



Legend

- Key Viewpoint
- County boundary
- Designated Landscape Boundary

Label	Name	Type
1	Wye Valley (England)	AONB
2	Llŷn	AONB
3	Bryniau Clwyd A Dyffryn Dyfrdwy/Clwydian Range and Dee Valley	AONB
4	Dyffryn Gwy/Wye Valley (Wales)	AONB

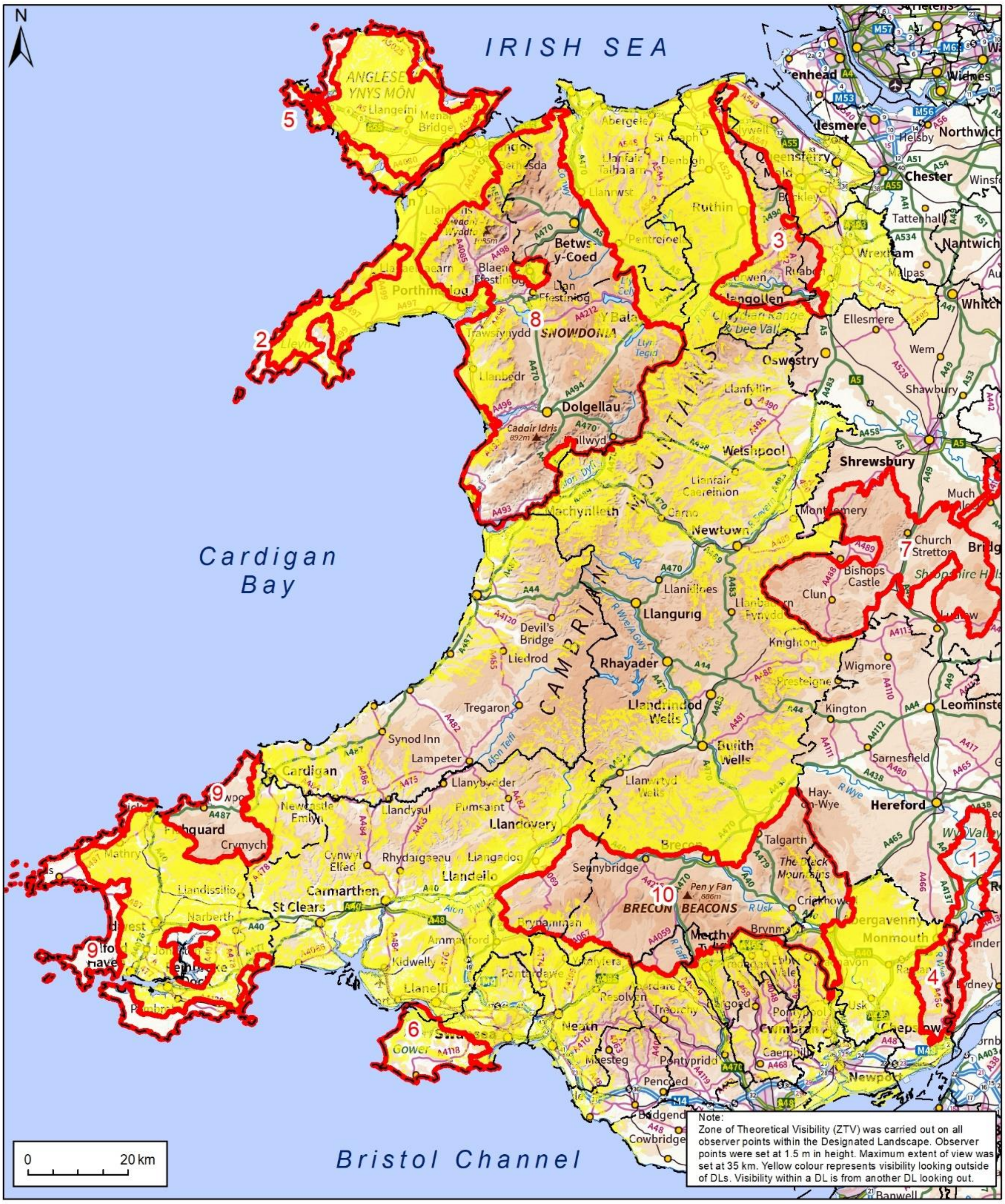
Label	Name	Type
5	Ynys Môn/Anglesey	AONB
6	Gŵyr/Gower	AONB
7	Shropshire Hills	AONB England
8	Eryri/Snowdonia	National Park
9	Arfordir Penfro/Pembrokeshire Coast	National Park
10	Bannau Brycheiniog/Brecon Beacons	National Park

Geo Smart Decisions

Appendix 8: Visibility from within all DLs

Combined ZTV results
Visibility across Wales from observer points within Designated Landscapes

Cyfoeth Naturiol Cymru
Natural Resources Wales



Legend

- Visible Areas
- County boundary
- Designated Landscape Boundary

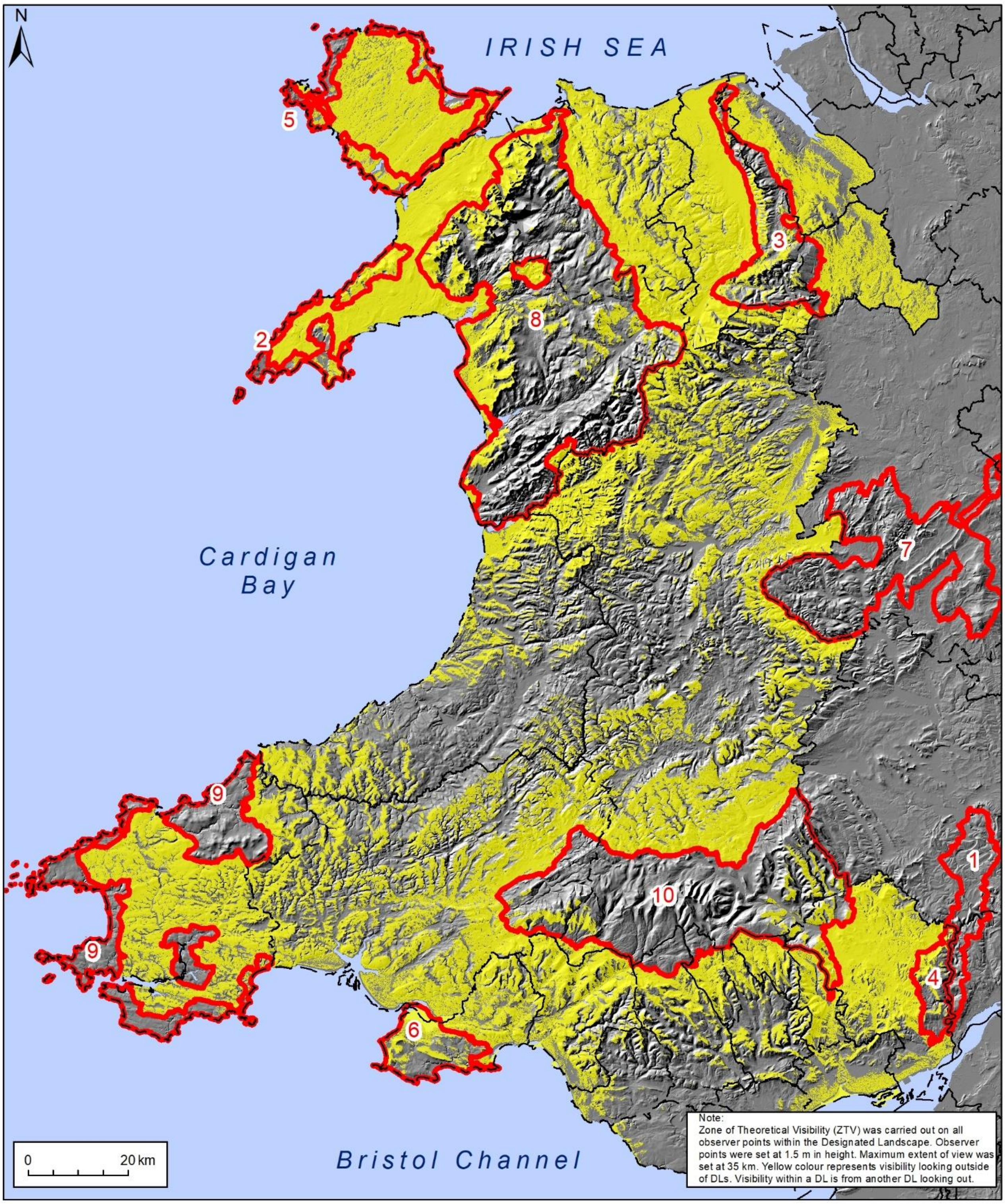
Label	Name	Type
1	Wye Valley (England)	AONB
2	Llŷn	AONB
3	Bryniau Clwyd A Dyffryn Dyfrdwy/Clwydian Range and Dee Valley	AONB
4	Dyffryn Gwy/Wye Valley (Wales)	AONB

Label	Name	Type
5	Ynys Môn/Anglesey	AONB
6	Gŵyr/Gower	AONB
7	Shropshire Hills	AONB England
8	Eryri/Snowdonia	National Park
9	Arfordir Penfro/Pembrokeshire Coast	National Park
10	Bannau Brycheiniog/Brecon Beacons	National Park

Geo Smart Decisions

Combined ZTV results
Visibility across Wales from observer points within Designated Landscapes

Cyfoeth Naturiol Cymru
Natural Resources Wales



Legend

- Visible Areas
- County boundary
- Designated Landscape Boundary

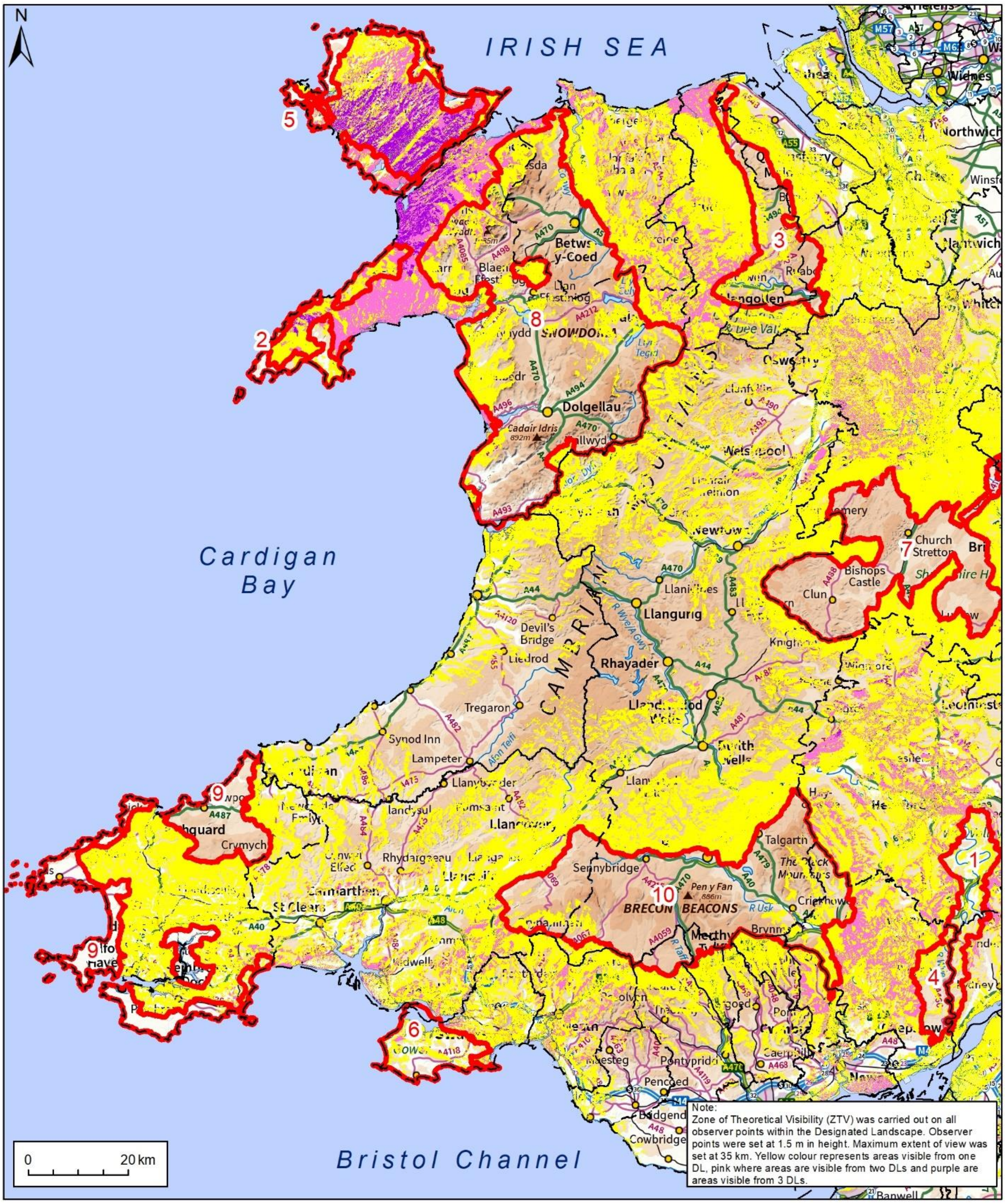
Label	Name	Type
1	Wye Valley (England)	AONB
2	Llŷn	AONB
3	Bryniau Clwyd A Dyffryn Dyfrdwy/Clwydian Range and Dee Valley	AONB
4	Dyffryn Gwy/Wye Valley (Wales)	AONB

Label	Name	Type
5	Ynys Môn/Anglesey	AONB
6	Gŵyr/Gower	AONB
7	Shropshire Hills	AONB England
8	Eryri/Snowdonia	National Park
9	Arfordir Penfro/Pembrokeshire Coast	National Park
10	Bannau Brycheiniog/Brecon Beacons	National Park

Geo Smart Decisions

Combined ZTV results
Visibility across Wales from observer points within Designated Landscapes

Cyfoeth Naturiol Cymru
Natural Resources Wales



Legend

County boundary
Designated Landscape Boundary
One DL visible
Two DLs visible
Three DLs visible

Label	Name	Type
1	Wye Valley (England)	AONB
2	Llŷn	AONB
3	Bryniau Clwyd A Dyffryn Dyfrdwy/Clwydian Range and Dee Valley	AONB
4	Dyffryn Gwy/Wye Valley (Wales)	AONB

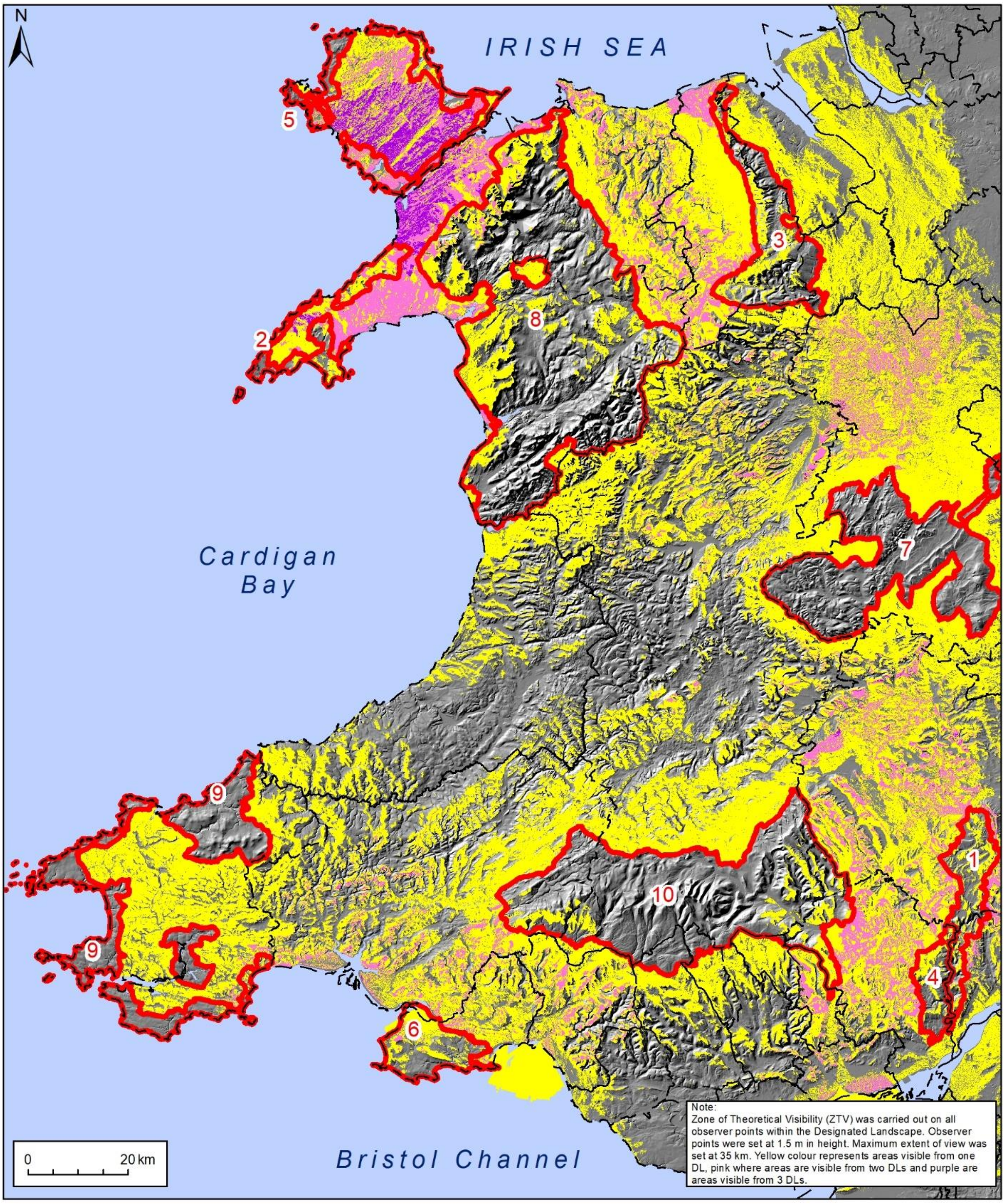
Label	Name	Type
5	Ynys Môn/Anglesey	AONB
6	Gŵyr/Gower	AONB
7	Shropshire Hills	AONB England
8	Eryri/Snowdonia	National Park
9	Arfordir Penfro/Pembrokeshire Coast	National Park
10	Bannau Brycheiniog/Brecon Beacons	National Park

Geo Smart Decisions

Combined ZTV results

Visibility across Wales from observer points within Designated Landscapes

Cyfoeth Naturiol Cymru
Natural Resources Wales



Legend

- One DL visible
- Two DLs visible
- Three DLs visible
- County boundary
- Designated Landscape Boundary

Label	Name	Type
1	Wye Valley (England)	AONB
2	Llŷn	AONB
3	Bryniau Clwyd A Dyffryn Dyfrdwy/Clwydian Range and Dee Valley	AONB
4	Dyffryn Gwy/Wye Valley (Wales)	AONB

Label	Name	Type
5	Ynys Môn/Anglesey	AONB
6	Gŵyr/Gower	AONB
7	Shropshire Hills	AONB England
8	Eryri/Snowdonia	National Park
9	Arfordir Penfro/Pembrokeshire Coast	National Park
10	Bannau Brycheiniog/Brecon Beacons	National Park

Geo Smart Decisions

Appendix 9: Additional Analyses – LANDMAP Landscape Areas

Generating additional observer points for LANDMAP Landscape Areas

After a review of the viewshed outputs generated for the LANDMAP Visual & Sensory Landscape Areas (LAs) and discussion with NRW staff, it was agreed that a review of the way in which observer points were generated for some, was required. The issue was particularly related to LAs that had had few ridge points, complex shapes and/or were low lying.

The first approach applied to generate more observer points in a systematic way across all of the LAs whilst still achieving efficiency in processing time and power was to use a grid system and to adjust the density of the grid depending on area (see table below).

Table 1: Variable Observer Point Grid

Landscape Area Size (Ha)	Grid Size (m)
< 5	30
5 - 10	50
10 - 250	100
250 - 1000	500
1000 - 5000	1000
> 1000	2000

A review of the resultant viewsheds however highlighted that large LAs with complex shapes did not generate representative viewsheds and another step was required. GSD then tested how the additional generation of observer points along boundaries might automatically generate a more appropriate set of observer points for these LAs. The resultant viewsheds from these boundary observer points were then integrated with the pre-existing rasters supplementing the viewsheds generated by the peaks and ridges observer points as well as the points generated from the grid approach.

Testing

Fifty LANDMAP areas were selected to include a range of shapes, comprising of simplistic circular, complex and string-like polygons. The term 'string like' here refers to the long, windy, and thin nature of the polygon, like a piece of string (Figure 1). The latter two, 'complex' and 'string-like' were found to most commonly represent the LAs that had unrepresentative viewsheds with the first and second observer point generation methods. Two ways to generate the boundary line observer points were tested, the first was the placement of points at fixed intervals (250 m was tested) along the boundary of each shape. The second was to extract the vertices of the boundary line, inherent in the data.

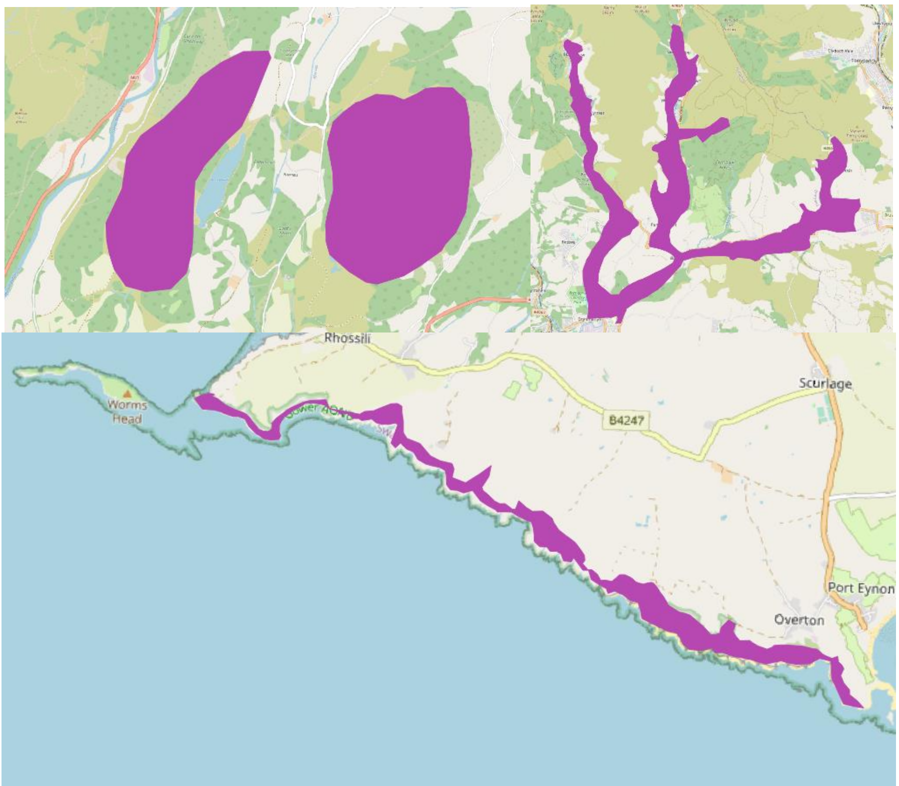


Figure 1: Examples of LANDMAP Landscape Area Polygon shapes that were selected for testing. *Top left:* Simplistic/Circular [SNPVS116], *Top Right:* Complex [CYNONVS148], *Bottom:* String-like [SWNSVS581]

Summary stats and examples of results from the 50 test areas

LANDMAP Visual & Sensory Landscape Areas (LAs) were selected from across the whole of Wales, including polygons from Anglesey, Brecknockshire, Conwy, Ceredigion, Carmarthenshire, Bridgend/Caerphilly/Rhondda, Denbighshire, Flintshire, Gwynedd, Monmouthshire, Montgomeryshire Merthyr Tydfil, Neath/Port Talbot, Pembrokeshire, Snowdonia, Swansea, Vale of Glamorgan and Wrexham (Figure 2 below).

Table 2: Summary stats of 50 test areas

LA Area min (ha)	LA Area max (ha)	LA Existing number of Observer Points Min	LA Existing number of Observer Points Max
13.94	8279.85	14	1083

Table 3: Average Number of Observer Points by generation method

Avg. number of existing Observer Points	Avg. number of Fixed Interval Observer Points	Avg. number of vertices Observer Points
133	156 (+17%)	850 (+539%)

Results across the 50 areas were quite varied, however, on average the boundary points at 250 m resulted in the generation of a similar number of observer points as that produced using the peaks, ridgelines, and grid density methods. When using the vertices along the boundary lines, the number of points generated was much higher, owing to the complex shapes of the areas. This resulted in a large increase in processing time required to generate the 50 viewsheds (1.5 hours compared to 7 hours).

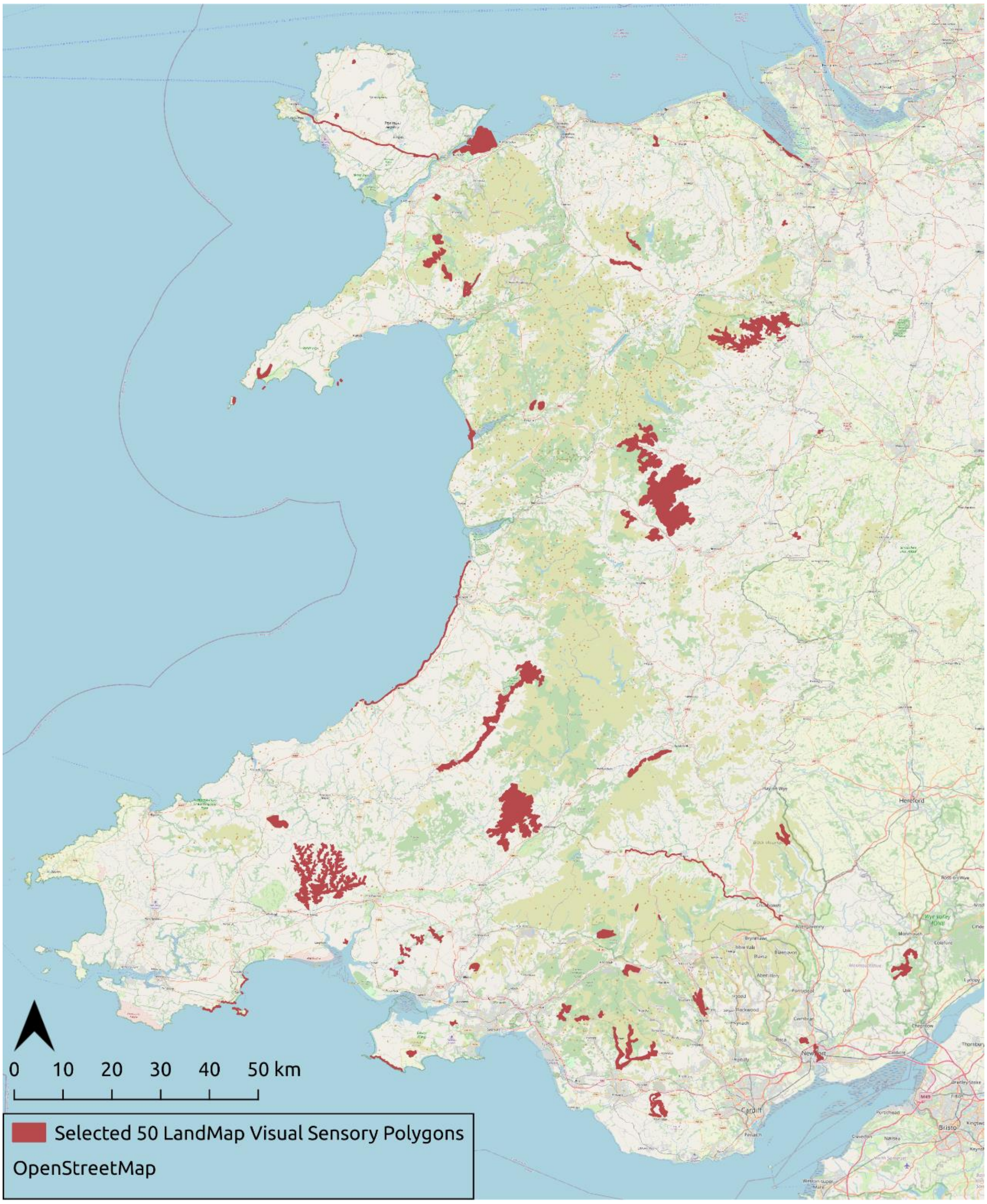


Figure 2: Map of selected Landscape Area Polygons

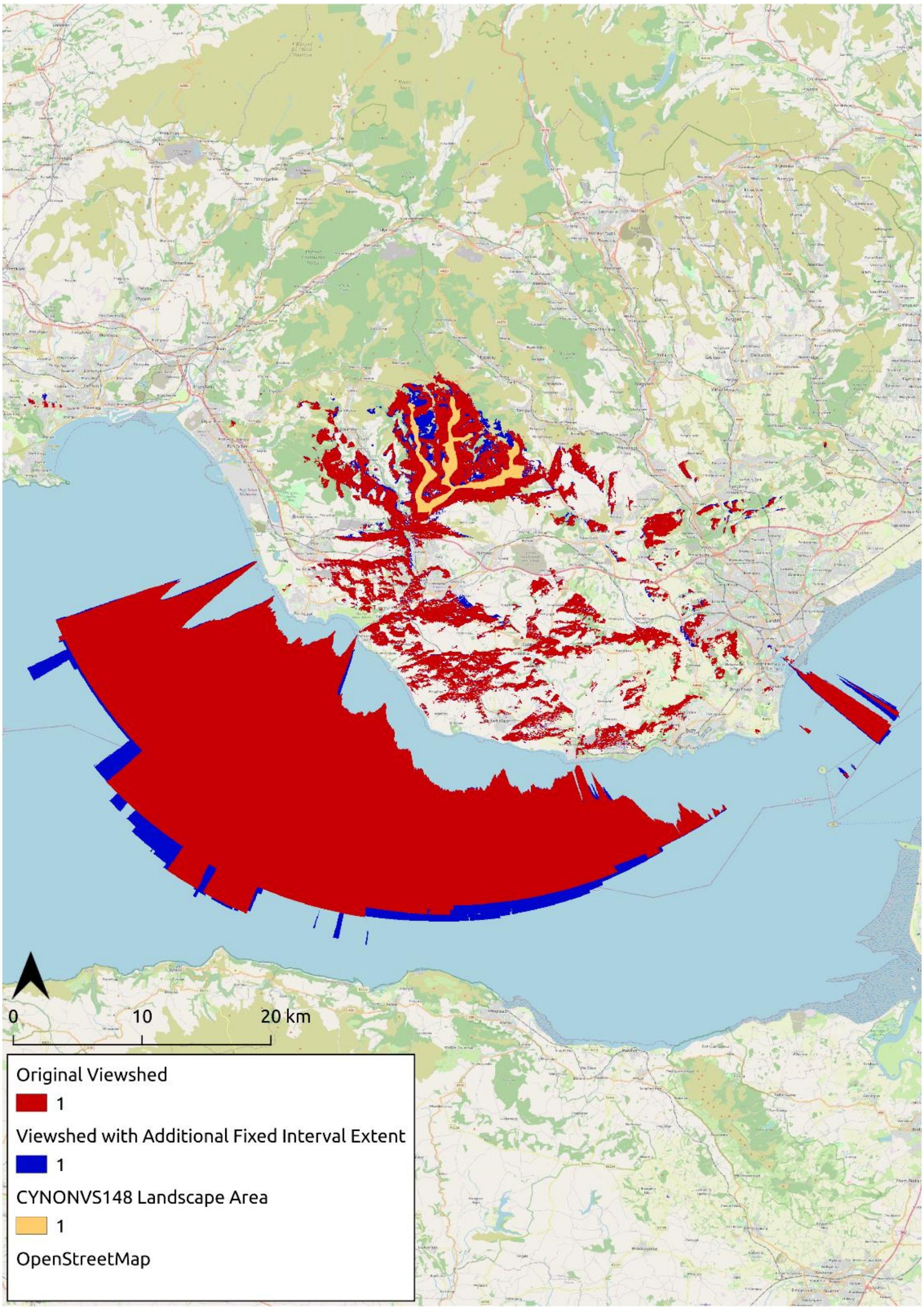


Figure 3: Example of LANDMAP Area CYNONVS148. Original viewshed extent is red whilst the improved version is in blue. Note all areas of the original viewshed are also included in the improved extent.

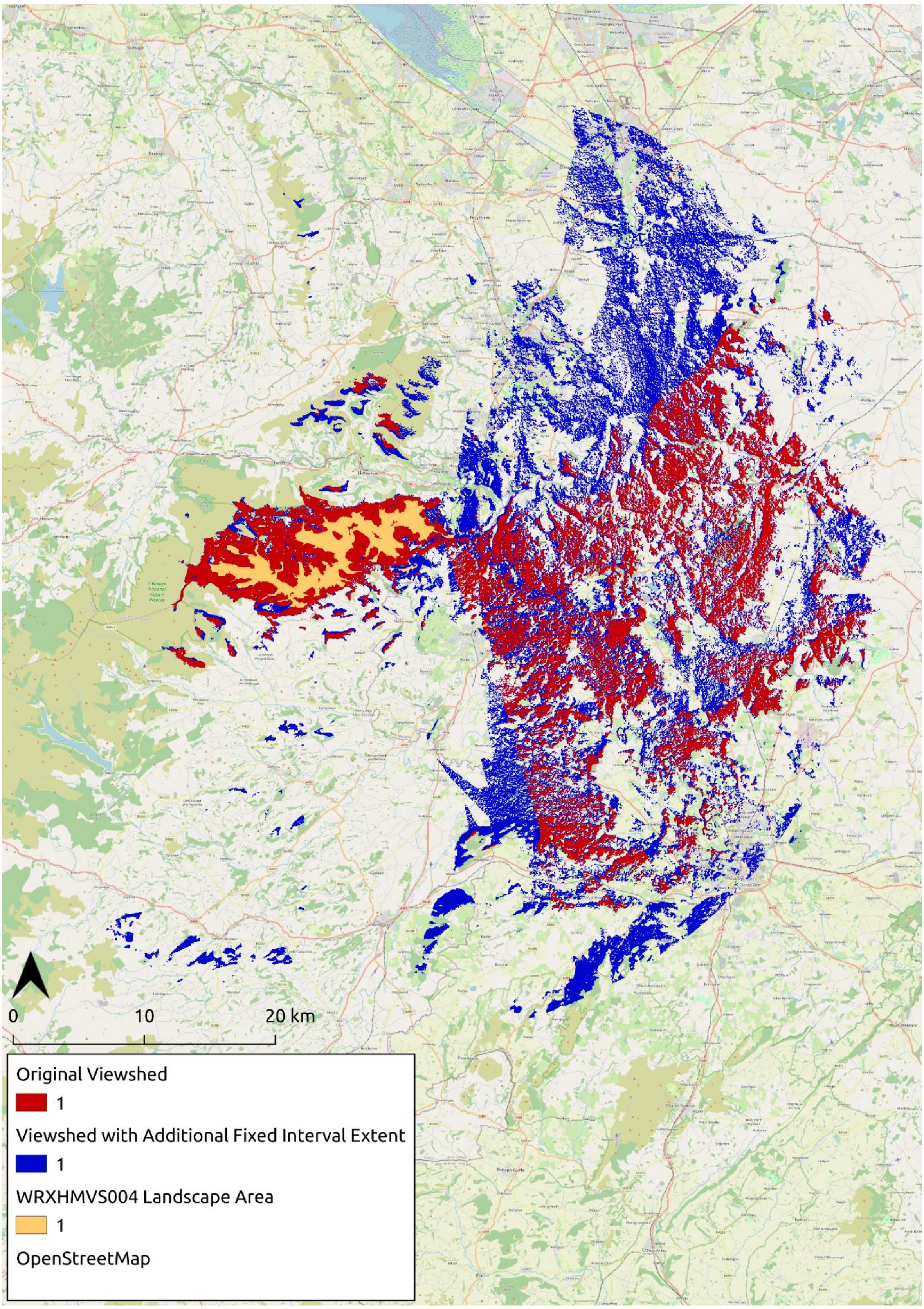


Figure 4: Example of LANDMAP Area WRXHMVS004. Original viewshed extent is red whilst the improved version is in blue. Note all areas of the original viewshed are also included in the improved extent.

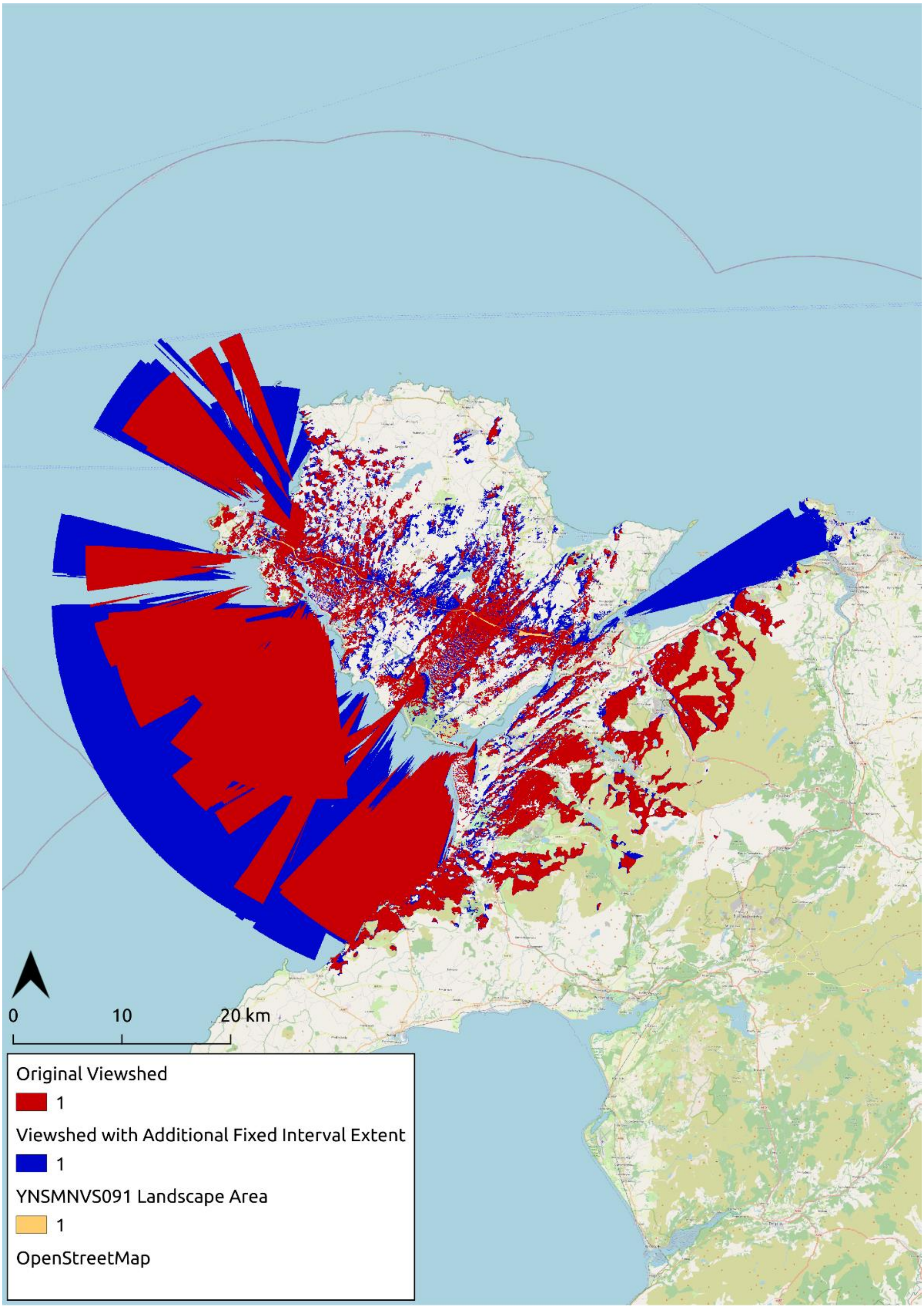


Figure 5: Example of LANDMAP Area YNSMNVS091. Original viewshed extent is red whilst the improved version is in blue. Note all areas of the original viewshed are also included in the improved extent.

Overview of results

Table 4: Comparing the number of observer points (OPs) generated alongside total area visible (by number of pixels) as identified by the respective viewshed generation methods. Percentage change in brackets.

	Fixed interval Difference (number of Observer Points)	Vertices Difference (number of Observer Points)	Fixed interval Difference (number of Viewshed Pixels)	Vertices Difference (number of Viewshed Pixels)
Min	-525 (-85%)	-87 (-67%)	-4696476 (-64%)	-4543052 (-63%)
Max	1203 (+826%)	6972 (+12914%)	833156 (+206%)	1030771 (+234%)
Average	23 (+73%)	717 (1041%)	-414433 (-21%)	-382142 (-15%)

Of the 50 areas tested, several were selected that represented the extremes of each category and then compared to examine the relative effects of the different approaches. These were (i) simplistic shapes, circular or square in nature, (ii) complex shapes which contained many angles and narrow channels, or (iii) string-like areas representing long and narrow polygons such as roads, river channels or coastal cliffs/beaches.

Table 5: Comparing the number of observer points generated and total area visible (by number of pixels) identified in the respective viewshed for the three different shape types

	Total number of Landscape Areas	Avg. Fixed interval Difference (number of Observer Points)	Avg. Vertices Difference (number Observer Points)	Avg. Fixed interval Difference (number of Viewshed Pixels)	Avg. Vertices Difference (number of Viewshed Pixels)
Simplistic	5	-18 (-29%)	8 (+13%)	-204805 (-47%)	-205136 (-47%)
Complex	4	435 (+444%)	3070 (+4333%)	28056 (+54%)	65561 (+63%)
String-Like	5	153 (+226%)	1918 (+2450%)	-355196 (+9%)	-233903 (+17%)

From the results, several observable features can be identified.

I. On average, where it is fixed intervals used to generate observer points along the polygon boundary or the use of vertices points as observer points, the viewshed generated in total is smaller than that generated from the initial method (peaks, ridges plus grid) (-21/-15%, Table 3).
II. There is also a noticeably smaller visible area identified from the vertices method (-15%), when compared to the initial method, despite a significant increase in observer point count (+539%, Table 3).
III. There is however, a large variation between the total areas visible, with a max increase of an observed viewshed area of 234% (Table 4). This verifies the initial concerns identified after the first set of viewsheds were generated; the concern was that some of the calculated viewsheds did not appear representative of the Landscape Areas using the first method to generate OPs and furthermore this was not completely solved by including gridded observer points.

IV. The results vary depending on area shape. Simplistic shapes were unaffected by the use of additional observer points generated along the boundary as the viewshed had already been accurately represented using the initial methods of generating observer points (-47%, Table 5).
V. Complex shapes benefitted enormously from the new approach. An increase of observer points on average by over 400%, yielding increased visible areas (represented by the viewshed and number of pixels) of 54-63% (Table 5).
VI. String-like shapes also saw an increased number of observer points (+226/2450%, Table 5); however, these areas saw less of an increase in visible area (+9/+17%).
VII. Using vertices to generate the observer points compared with the fixed interval approach resulted in slightly more visible areas being represented in the respective viewsheds for complex and string-like LAs (9% and 8% difference respectively, Table 5), however this comes at a relatively massive computational cost (+4333 and +2450% increase respectively in points) and therefore consequentially, processing time.

Generating the 'final version' viewsheds

Viewsheds were generated for each LANDMAP Visual & Sensory Landscape Area (LA) of Wales (1991 polygons) using the observer points (OPs) created from the fixed interval methodology. Total viewshed area for each LA was then calculated by taking the cumulative viewshed from each of the previous approaches used to generate points (the original ridge line and peaks approach and the grid-based approach) and adding these to the outputs from the boundary points OP generation method.

The generation of additional observer points, spaced at fixed intervals (250 m) along each Landscape Area boundary, was successful on multiple fronts. Firstly, the results demonstrated increases to the total area of viewsheds for many of the areas, particularly those that had fewer observer points owing to their shape. Secondly, however, the process uncovered a technical error in the calculation of final viewsheds, owing to the presence of Not-a-Number (NaN) values within some rasters. This value caused an unexpected behaviour within GDAL's raster calculation and consequently, the entire band was omitted when calculating cumulative viewshed extents. This resulted in a lack of viewshed pixels being carried through to the final dataset for some areas and this was also corrected for as part of this additional work.

The viewshed calculations were recomputed using the original viewshed outputs from each model, to avoid incorporating the identified error within GDAL. No data values were also manually edited prior to calculation to avoid repeat issues. Furthermore, each area was rasterised and included within the viewshed to avoid missing data within the polygons, as this was initially only implemented during the first model which was not applied to all LAs (in the first pass, approx. 100 LAs were not processed as these did not have OPs generated for them).

The change in viewshed was calculated according to equation 1 below where *c* is the boundary interval viewshed, *a* is the original viewshed and *b* is the gridded observer point viewshed. This allowed for the maximum existing viewshed to act as the baseline, therefore including Landscape Areas with only one previous viewshed.

Equation 1: $\Delta = c - max(a,b)$

Table 5. Summary Addition Statistics of ‘fixed interval’ Observer Point Count.

Mean Addition (%)	Minimum Addition (%)	Maximum Addition (%)
101%	8.89%	2971.4%

Table 6. Summary statistics of ‘fixed interval’ Viewshed Pixel Change.

Mean Difference (*Δ*)	Minimum Difference (*Δ*)	Maximum Difference (*Δ*)	1st Quartile Difference (*Δ*)	3rd Quartile Difference (*Δ*)
10.9%	<0.1%	94.2%	2.1%	13.3%

As shown in the table above, the results vary in success, with some polygons having a negligible improvement from the addition of ‘fixed interval’ observer points whilst others observed a doubling in the resultant area of visible areas. These results highlight the effectiveness of the initial observer point generation approach, as the mean increase of 10.9% viewshed comes from a mean increase of 101% in observer point count. As from the testing findings, the areas likely to have benefitted from this extra analysis the most, are the areas with complex or string-like shapes, where observer points generated through previous methods did not extend to all the vertices or reaches of the polygon.

When trying to identify a relationship between viewshed change (in area) and the total area of the original LANDMAP Landscape Area, perimeter length or number of vertices, no relationships could be found (Figure 1 below). Whilst this would suggest that the addition of fixed interval points was universal in the ‘improvement’ of the resultant viewsheds, it may imply that these metrics are unlikely to accurately describe the complexity of the shape itself. Specific metrics that can numerically separate complex and simplistic polygons maybe useful in the thresholding of observer point spacings to improve efficiency, however, explorations into these metrics have only been experimented within geospatial academia and such are beyond the scope of this study.

As the change in identified viewshed extent area was highly varied amongst the Landscape Areas, relationships between this difference and features of the polygons were investigated. Polygon statistics such as area size, perimeter and number of vertices were selected, however, no correlations were found. This was interesting, as it highlighted the difficulty in quantifying the complexity of the polygon areas, particularly in a single value. Perhaps using a specific metric for polygon complexity, such as that proposed by Brinkhoff *et al*. (1995), may allow for more targeted quantities of observer points to be placed, relative to the polygons, particularly when working with complex polygons, such as the LANDMAP dataset. This does not however, answer the question of placement, as the initial work conducted in this project highlighted the important of strategic point placement for optimal viewshed. Ultimately, work to improve and parallelise the viewshed algorithm would enable dense observer point grids to be used to generate observer points. This would remove the need for polygon analysis and variable observer point placement entirely and would have been used in this study if that were a viable option.

Final testing

An additional check was made to a further 50 Landscape Areas using a random sample of viewsheds generated to first verify whether all previous identified pixels were carrying through the calculations, thereby verifying the fixes to the GDAL bug were successful, and secondly, to verify whether an improvement to the viewsheds was observed (measured by a clear increase in viewshed size) (Figure 6). This was the case for all 50 LAs that were tested, again quite notably, those LAs that had a ‘complex’ shape (Figures 7, 8, 9).

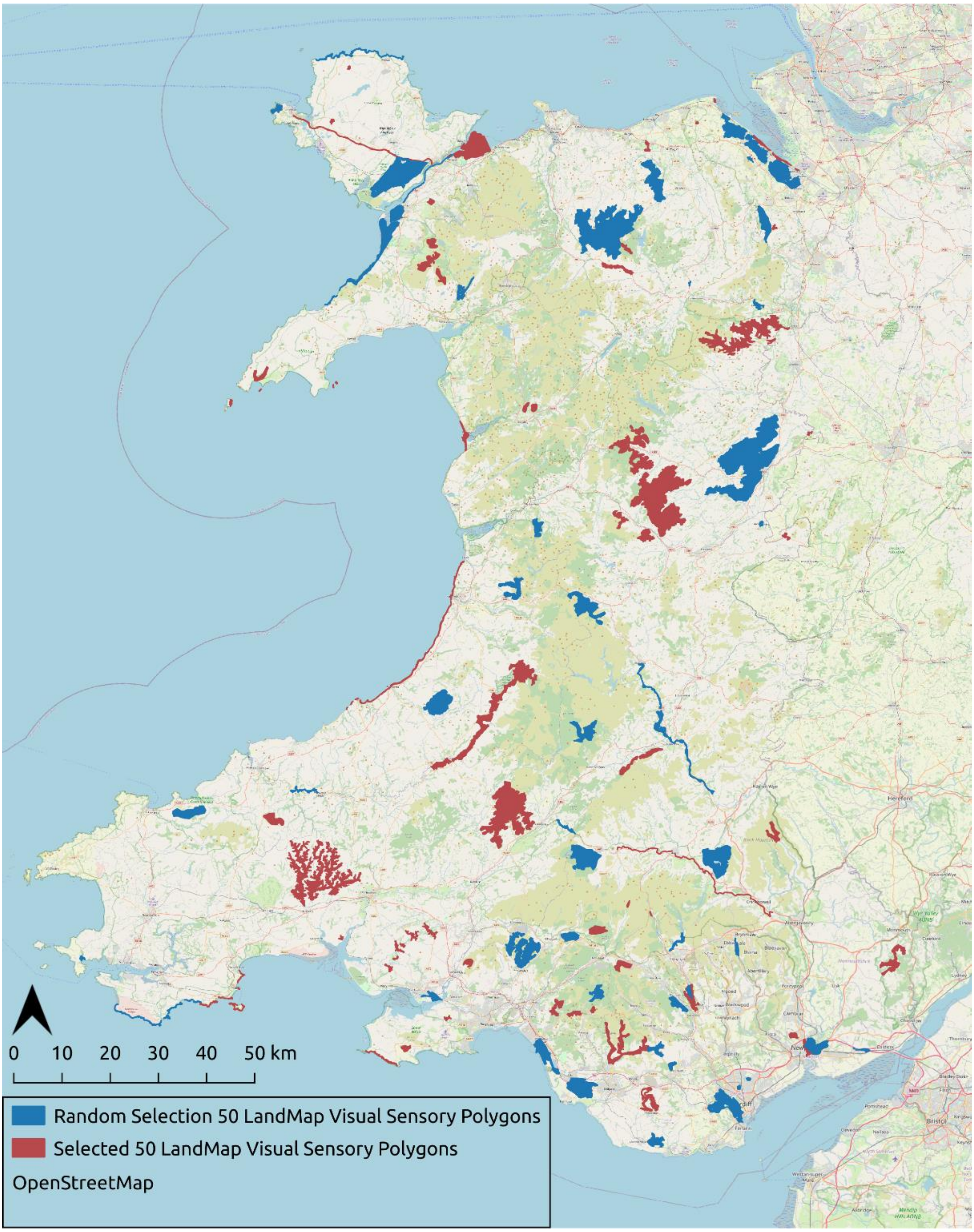


Figure 6: Map of 50 selected Landscape Area Polygons in red, along with 50 additional selected at random in blue.

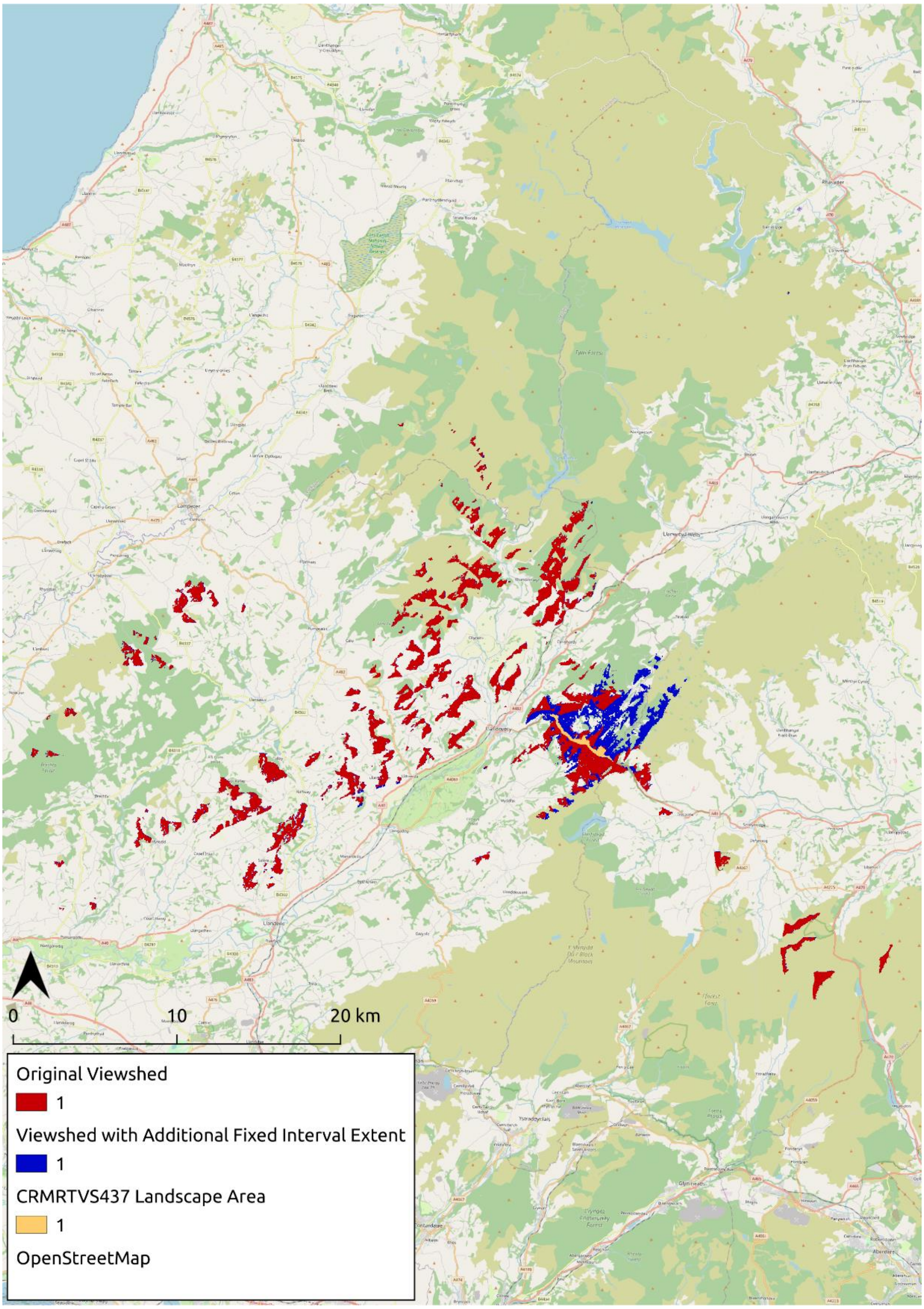


Figure 7: Example of a randomly selected site: LANDMAP Area CRMRTVS437. Original viewshed extent is red whilst the improved version is in blue. Note all areas of the original viewshed are also included in the improved extent.

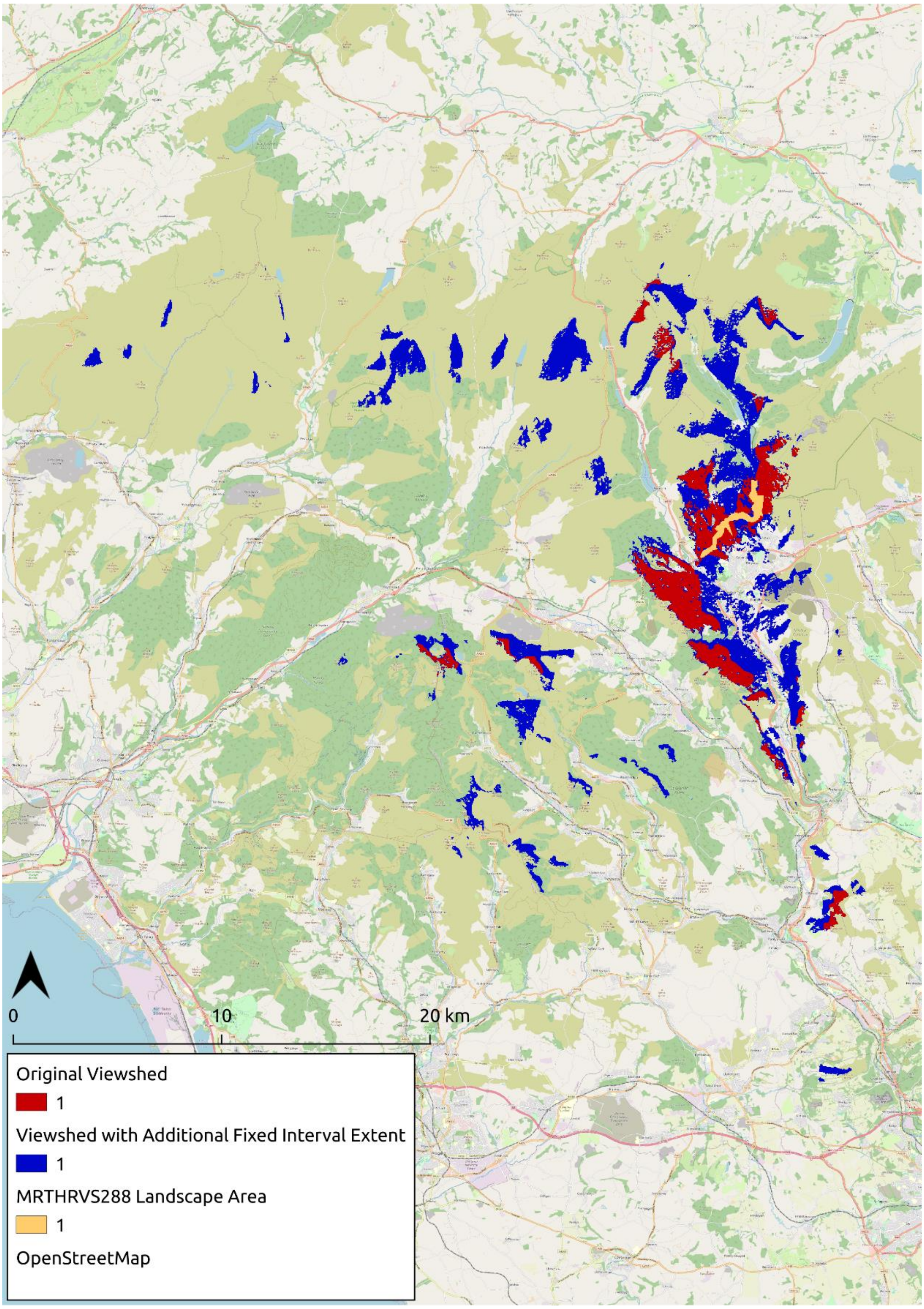


Figure 8: Example of a randomly selected site: LANDMAP Area MRTHRVS288. Original viewshed extent is red whilst the improved version is in blue. Note all areas of the original viewshed are also included in the improved extent.

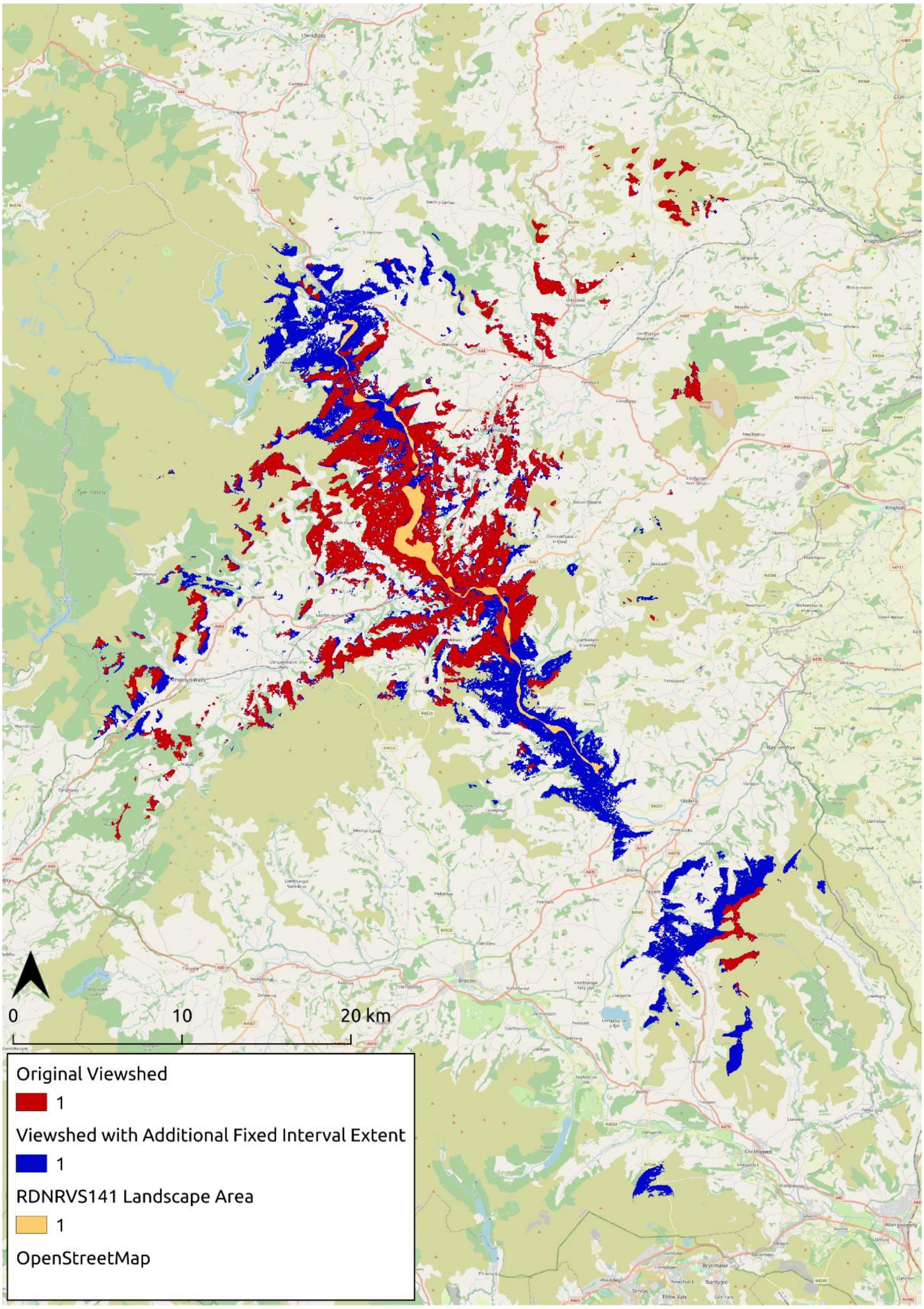


Figure 9: Example of a randomly selected site: LANDMAP Area RDNRVS141. Original viewshed extent is red whilst the improved version is in blue. Note all areas of the original viewshed are also included in the improved extent.

Summary

Reviewing the methods used to generate the viewshed for Wales' LANDMAP Visual & Sensory Landscape Areas was successful for two reasons. Firstly, the outputs were refined by the recomputing of viewsheds by avoiding 'NaN value errors'. Secondly, the addition of the extra observer points generated using the 'fixed interval' method increased a quarter of the Landscape Areas' viewsheds by >13%, sometimes nearly doubling the estimated visible area from a single LA. This approach was tested on 50 LAs of different shape type (circular, complex and string-like). The use of the fixed interval method to generate OPs was rolled out across all of the LAs across Wales (1991 polygons) owing to the best observed increase in extent, relative to the increase in computational time. Final checks to test and validate this new OP generation approach were carried out on the viewsheds generated for another 50 LAs across Wales.

The use of the additional Observer Points generated through the fixed interval method represents an effective method for identifying visible extents of Landscape Areas across Wales. Any further improvements were observed at the cost of greater computational time, and as such any further work would be best placed in the development of a new viewshed generation algorithm that would allow parallel computation of viewsheds. This way, the optimal generation and placement of OPs would be redundant as a substitute dense grid could be used instead.

References

Brinkhoff, T., Kriegel, H.P., Schneider, R. and Braun, A., (1995) Measuring the Complexity of Polygonal Objects. In *ACM-GIS* **109**