A Geographical Analysis of the Intervisibility of the Coastal Areas of Wales for Characterizing Seascapes

David R Miller and Jane G Morrice

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The Macaulay Institute
Craigiebuckler
ABERDEEN
AB15 8QH

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Summary

The conjunction of water and land provides unique character to landscape, and the importance of the presence of water in a scene has been documented by a number of authors (Shafer and Bush 1977; Wherrett, 2000). This strategic assessment of the coastal zone and characterization of 'Seascapes' around the Welsh coast uses a geographical analysis of the visibility of the coast to the landward and seaward side of the coastline.

A Digital Terrain Model (DTM) is used as the basic input, from which four assessments of visibility are derived:

1. visibility of sea from the land;
2. visibility of land from the sea;
3. influence of land elevation on visibility from the sea;
4. and, a classification of coastal horizons.

The results of the analyses are summarized below.

<u>Visibility of sea from the land</u>

The visibility of the sea from the land is based upon a 1 km x 1 km regular grid of points in a band 10 km seaward of the coastline. The number of sample points visible from every 50 m x 50 m cell inland of the coastline is recorded to provide a score of sea visibility from the land.

The land from which the most extensive views of the sea are available is predominantly around the north and west coast (excluding Anglesey), extending from approximately Llandudno, west along the Lleyn peninsula south towards Aberystwyth and Fishguard. The coastline in the vicinity of Swansea also offers sites of high visibility of the sea, but the south-west coastal area, around Pembroke has few extensive sea views inland from the coast.

The distribution of the visibility of the sea from the land with respect to the aspect of the terrain shows that the higher visibility levels are most extensive in a western arc between south-west and north-west. Visibility of the waters within 10 km of the coastline are calculated to be visible up to approximately 40 km inland at Corn Du in the Brecon Beacons National Park.

Visibility of land from the sea

The calculation of the visibility of the land from the sea uses a sample of points at 1 km x 1 km intervals seaward of the coastline with a 40 km radius of view. For every 50 m x 50 m cell in a 10 km distance seaward of the coastline, the number of the sample points that are visible is recorded, providing a score of the visibility of the land from the sea.

The areas from which most land is recorded as being visible from the sea are predominantly associated with embayments, such as Swansea Bay or the Tremadog Bay, the eastern stretch of the Bristol Channel, and in the approaches to the Menai Straits. These areas tend to be where there is high land adjacent to sea or where there is land on more than one side.

Sections of the offshore areas from which the coastal land is less visible are where the coastline is linear or there are headlands, such as the southern coast of Cardigan Bay between Fishguard and Aberystwyth, which includes the Ceridigion Heritage Coast.

The analysis reported above is based upon a separation of the coastal zone between land and sea. However, the inter-tidal zone is wide in many areas due to the presence of sands and mud-flats. Further, an observer's understanding of 'the coast' is not necessarily constrained to the coastline as mapped. Therefore, a trial analysis was also carried out which treated the areas either side of the coastline together. Nonetheless, similar geographic areas to the first analysis are identified as being of high visibility (*e.g.* in the vicinity of the Menai Straits).

Influence of land elevation on visibility from the sea

The influence of the elevation of the higher land is assessed by calculating the vertical angles to the horizon in different directions for a sample of points within 10 km of the seaward side of the coastline. The most extensive areas of influence are in Tremadog Bay, Barmouth Bay and the eastern approaches to the Menai Straits, and to a lesser extent around Fishguard and the southern side of Cardigan Bay.

The areas on which the elevation of the terrain appears to contribute least to the view are in a band between 5 km to 10 km off the south-west coast of Wales, stretching from approximately the Gower Peninsula to St. David's Head.

Classification of coastal horizons

To assess the contribution made by water within the horizontal extent of view, three measures of the characteristics of the coastline are derived:

1. The extent of the horizontal view occupied by the sea at a 10 km distance, as measured by proportion of the circumference of a circle around an observer.

2. The extent of the horizontal view occupied by the sea at a 6 km distance, as measured by proportion of the circumference of a circle around an observer.
3. The length of coastline that is visible within 10 km of the observer.

The results of the first two measures of coastline characteristics show that the most open views are from land within 1 km of the coastline which also slopes towards the water. These areas include that south of Caernarfon, south of Llanbedr, in the vicinity of Prestatyn, and sections of the east coast of Anglesey, and the north coast of the Lleyn Peninsula. Within the 6 km distance of view, the southern coast of Cardigan Bay, the Gower Peninsula and the land east of Newport are also shown to provide among the widest views of the sea. Views of the water are relatively narrow and restricted in parts of south and south-west Wales, such as the area south of Pembroke, reflecting the plateau surface of the land from which some of the sample observations were made.

The areas from which the longest stretches of coastline may be visible are, east of Prestatyn, the entrances to the Menai Straits, the north-east of Cardigan Bay, the east side of Carmarthen Bay and east of Newport. The extent and shape of the Daugleddau estuary has also resulted in measured lengths of visible coastline that are longer than for other river valleys. The effect of lines of cliffs, frequent headlands, or shallow sloping terrain inland of the coast is to limit extensive views of the coastline. Areas such as the land immediately inland of the southern coast of Cardigan Bay and the south-west coastline of Wales offer views of the shortest lengths of coastline, within a 10 km radius of view.

Conclusions

For observers close to the coastline the horizontal extent of sea views would be substantially greater than that reported in this study, although on the coast the resolution of the input data may be a more significant issue. Indeed the scale and resolution of the input DTM data are the most important constraints on the analyses and their interpretation should recognise the limited detail and variation in the terrain surface that can be represented by 50 m x 50 m cells.

The methods used, or developed, within this study provide a basis for identifying where, and to what extent, visibility between land and sea varies geographically. The results could be used in the classification of the coastal zone for use in strategic planning and provide one means of defining the geographic extent of the coastal zone, at least with respect to its visibility.

In terms of methodological developments, geographic analyses have been applied to several new applications in the course of this study. Although a number of methodological issues remain outstanding, and their impact upon the results have not been comprehensively evaluated, the new types of data that have been derived for the coastal zone can enable complementary ways of describing and characterizing the coastal landscape at strategic or tactical levels of decision making. The outputs from the seascapes work provide one context for landscape character assessments and the modelling of landscape preference, which in turn would enable the results to contribute towards a greater understanding of the role that coastal views play in the Welsh landscape.

1. Introduction

The conjunction of water and land provides unique character to landscape. The rivers and lakes of Wales are landscape elements that provide contrast and a sense of place, and the conjunction of sea and land also provides an equally important element in the Welsh landscape. It reflects, and magnifies, the continuous changes in light and weather which contribute characteristics that the land presents to the sea, such as coastal views.

'Seascape' is a term which has not been closely defined, and its characterization and assessment are not normally treated separately from that of landscape. Nevertheless, the coastal and marine landscapes possess several distinct characteristics which justify specific analysis. This is especially so because of the opportunities and threats facing our coastline, both natural and through impacts of man's activities with, for example, the development of offshore windfarms or oilrigs.

There are three tangible components to Seascape:

1. the visual content and quality of the conjunction of sea and land;
2. the view to the sea from the land;
3. the view from the sea to the land.

Many of the most scenic areas of Wales are characterised by their close proximity to the sea, and affected either by direct views or a sense of the coastal environment gained from the atmosphere, in the vegetation or other indicators such as the presence of sea birds. The effect of the sea is strengthened for an island such as Anglesey, a peninsula like the Lleyn, and anywhere where the coast is indented to form estuaries or bays. The contribution of the land to a seascape is particularly important where land faces land across a body of water.

To assess the visibility of coastal areas from the sea, and the contribution of the sea to coastal views, the concept of Zones of Visual Influence (ZVI) and an assessment of landscape visibility (Miller and Law, 1997) have been extended to an assessment of intervisibility of sea and land for the coastline of Wales. The purpose is to reveal where the levels of intervisibility of land and sea are highest in inshore areas and the coastal hinterland.

This report provides an outline of the methodologies developed, the data used and a summary of the results obtained. Finally, the limitations of the methods are discussed and improvements proposed for several aspects of the work.

2. Data

The digital terrain dataset used in this study is the Ordnance Survey 1:50 000 Panorama dataset (Ordnance Survey, 1996), which is in a raster format with a spatial resolution of 50 m x 50 m and a vertical resolution of 1 m. The accuracy of the DTM has been reported as 3 m Root Mean Square Error (RMSE) by Ordnance Survey (Ordnance Survey, 1996). A representation of the coastline came from the Ordnance Survey 1:10 000 Land Line dataset (Ordnance Survey, 1997). These datasets were converted into either vector or raster formats suitable for use in the ESRI ArcInfo or ArcView software packages (ESRI, 1998).

The Panorama dataset was selected for use in the analyses of seascapes for two reasons:

1. The DTM is available for all of Great Britain, so can be used with consistency across large areas.
2. The quality of the DTM has been the subject of research by a number of authors and thus something is known about its limitations.

However, the same methodologies can be used for DTMs at other scales (*e.g.* Ordnance Survey 1:10 000 DTM (Ordnance Survey, 1997)) or from alternative sources (*e.g.* photogrammetrically derived (Miller, 1999)).

3. Methodology

The analysis of intervisibility of land and sea was split into three sections: 1. visibility of sea from the land; 2. visibility of land from the sea; and 3. a classification of coastal views. All of the analyses used the 1:50 000 OS DTM (Figure 1) as the principal input data, and the intervisibility functions of ERDAS IMAGINE (ERDAS, 1999), or ESRI ArcInfo GRID (ESRI 1998).

The principal analysis used is the derivation of a surface of relative visibility at a resolution of the input DTM (50 m x 50 m). The analysis does not calculate the number of cells visible from each other, because the computing overheads would currently render this impractical. However, a method has been developed which uses a regular grid of points at a lower resolution than that of the source DTM as the targets to be counted from every 50 m x 50 m DTM cell. This approach provides a surrogate to the counting of every cell from every cell, and outputs an index of relative visibility for each cell.

A 1 km x 1 km sample of points was used as input to the visibility census calculations. This interval was decided upon after tests undertaken for work on landscape visibility for Scottish Natural Heritage (SNH), and in research into methods for assessing the visual impact of changes in land use (Miller *et al.*, 1995).

The hardware platforms on which the processing was undertaken were Sun Ultra 80, Ultra 60, Ultra 20 and two Ultra 10 workstations. The computational requirements for deriving a census of landscape visibility are such that the processing is highly inefficient when analysing all of Wales as a single dataset. This is because of the extensive hardware memory requirements of the software, which usually results in substantial 'swapping' of data in and out of memory and a consequential slowing of the analyses.

The approach adopted was to split Wales into four, five or six separate, but overlapping areas, and undertaking the visibility analyses simultaneously on several different workstations. This enables a greater degree of flexibility in managing the processing loads in order to minimize the risk of intermittent computer failure (and thus a loss of processing output), and faster throughput of the data. The negative impact of this approach is a need to divide the dataset into areas that overlap by twice the distance of the radius of view being used in the calculation (*e.g.* if the radius of view was 10 km, the overlap between each area was 20 km). However, the total time required to process all of the sub-areas, and the duplication in the processing imposed by the need for overlapping areas, is considerably less than attempting to process all of the area of Wales in a single run.

3.1. Radius of view and observer height

An assumption made for all analyses was that the observer would be 1.8 m above ground level, for observations made from either land or sea. A standard radius of view (10 km) was also used for all of the analyses undertaken, but alternative radii were also used for different purposes in each of the analyses. This was based upon an estimate of the distance to the horizon for a viewer at sea level on the coast. Table 1 shows some examples of distances to the horizon, with the observer assumed to be at sea level (horizon at 5.5 km), 6 m above sea level (horizon at 10 km), and from the top of Mount Snowdon (horizon at 134.9 km).

Table 1 Examples of distance to the horizon for different heights of object or observer.

Height of observer (m)	Height of object (m)	Distance (nautical miles)	Distance (km)	Example
1.8	100	25.1	46.4	Man-made structure
1.8	50	18.6	34.4	Man-made structure
1.8	1.8	5.9	10.9	Two observers of equal height and elevation
1.8	0	3.0	5.5	Observer on beach
1085.0	0	72.8	134.9	Top of Mt. Snowdon
892.0	0	66.0	122.3	Top of Cadair Idris
311.0	0	39.0	72.2	Top of Mynydd Caregog

The viewing radius of 10 km provided a basis for assessing areas of greatest concentration of intervisibility between land and sea in the area around the Welsh coast, whilst being computationally tractable. To illustrate the differences between horizon distances for different heights above sea level, Figure 2 shows the Welsh coast, with a 10 km buffer, and theoretical horizons for the visibility from three example sites, from the tops of Mount Snowdon, Cadair Idris and Mynydd Caregog. However, this illustration takes no account of the feature size that would be required for it to be observable at distances of up to 134 km, nor the likelihood of the weather conditions that would also be required.

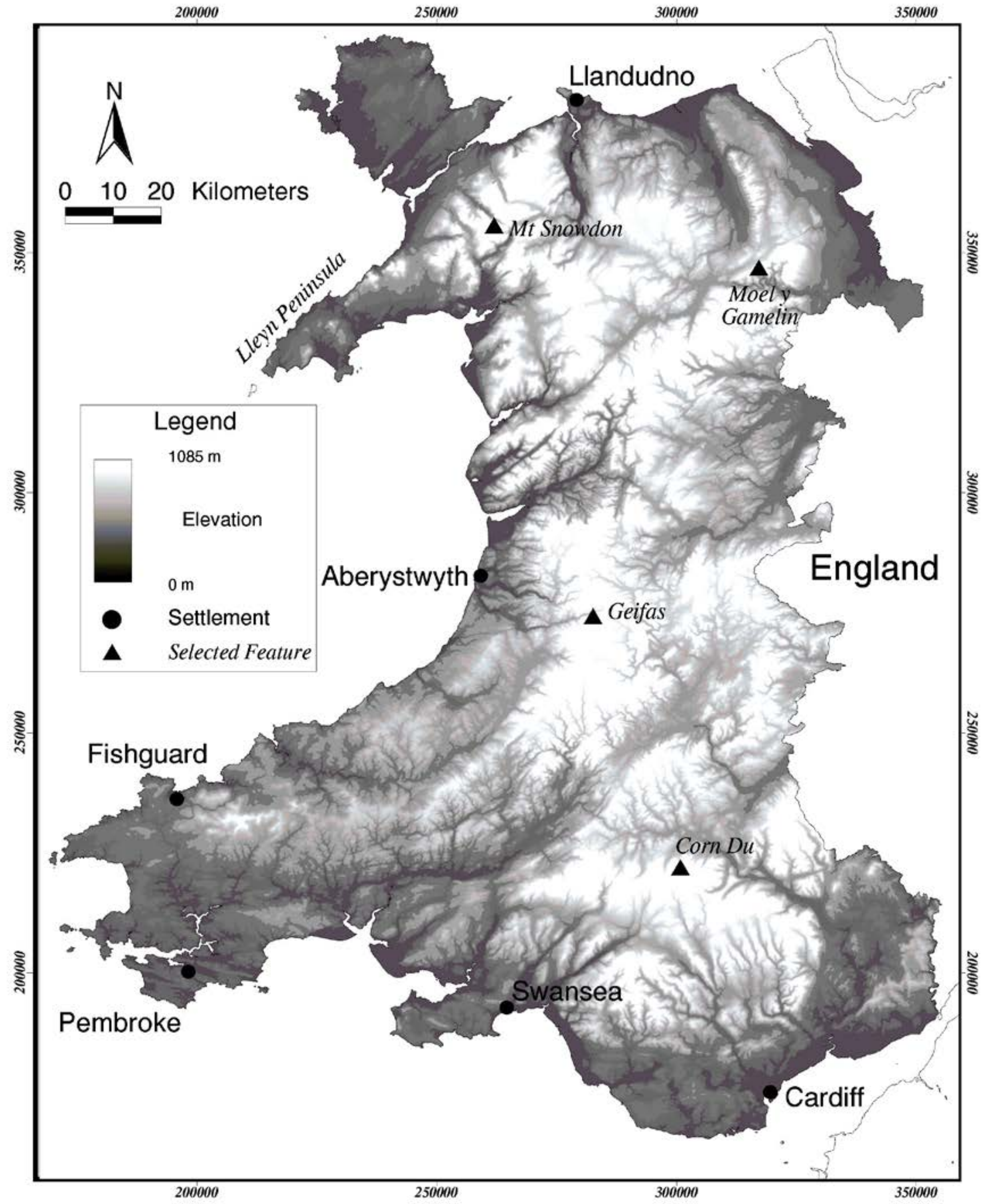


Figure 1 Digital terrain model of Wales (source: 1:50 000 Panorama dataset, Ordnance Survey, 1996).

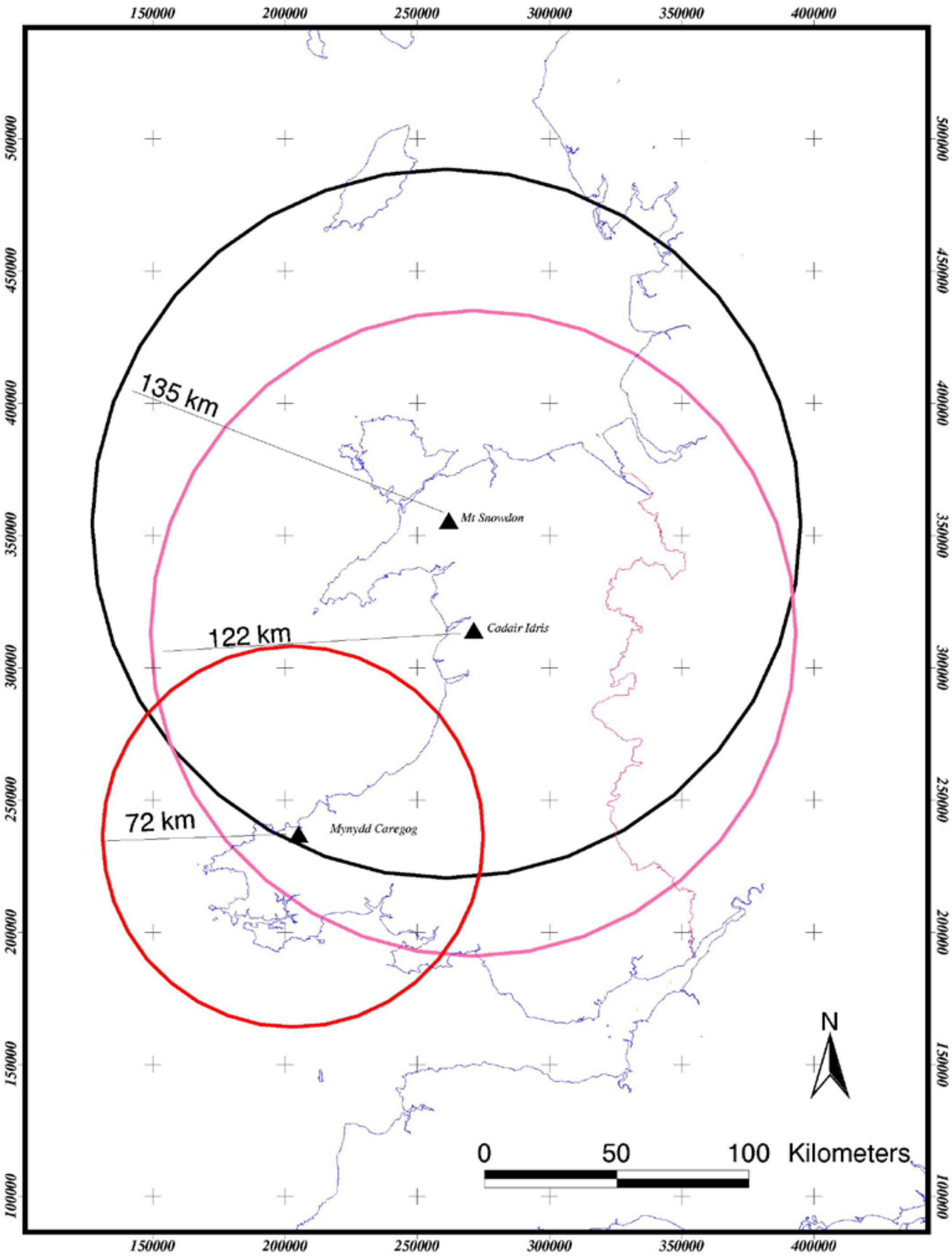


Figure 2 Theoretical distance to the horizon from selected locations.

3.2. Analyses of Visibility

The handling of geographic data in a digital form has provided a number of different ways of quantifying scene content and the use of visibility functions within GIS provides the basic means of estimating the extent and location of land which is visible to an observer or from where a feature may be visible (DeFloriani and Magillo, 1994; Fisher, 1996). Assessing the extent to which features are visible in the landscape, or indices of landscape visibility, have also been reported by authors including Franklin and Ray (1994), and Kidner *et al.* (1997).

DeFloriani and Magillo (1994) describe the use of Triangular Irregular Networks (TINs) data structures for the derivation of surfaces of 'continuous visibility' (based upon the area of the viewshed related to a facet of a TIN), with particular attention to the nature of the algorithms used in its derivation. They note that the time taken to undertake such analyses is sensitive to dimensions and detail of the input data, and that using regular sized grids can be computationally expensive, suggesting that parallel processing of the data may be an appropriate means of improving the efficiency of the analysis (Teng *et al.*, 1997).

The new method used to model the geography of seascapes is to derive the relative visibility of the terrain from a DTM, by calculating the intervisibility of points from either the land or from the sea, and assessing how visible every point is from every other point, at a spatial resolution of 50 m x 50 m. The output is a score for each 50 m x 50 m cell, which is related to low or high levels of visibility, as described in Miller and Law (1997). Figure 3 shows the output of this calculation for Wales with respect to the visibility of the land as viewed from the land. The brighter tones relate to areas of higher visibility, for example on the open valley sides of the Vale of Clwyd, compared to the darker areas which are less visible, such as the more enclosed valley sides (*e.g.* the south-east facing slopes of Cadair Idris).

The method for deriving the visibility of land has been modified to derive visibility levels of the coastal area of Wales by including the area up to 10 km offshore within the calculation. This enables one approach to the derivation of a surface of relative visibility (from low to high) of the land from the sea, and the sea from the land. Descriptions of each of the three analyses undertaken to assess the intervisibility of land and sea are described below.

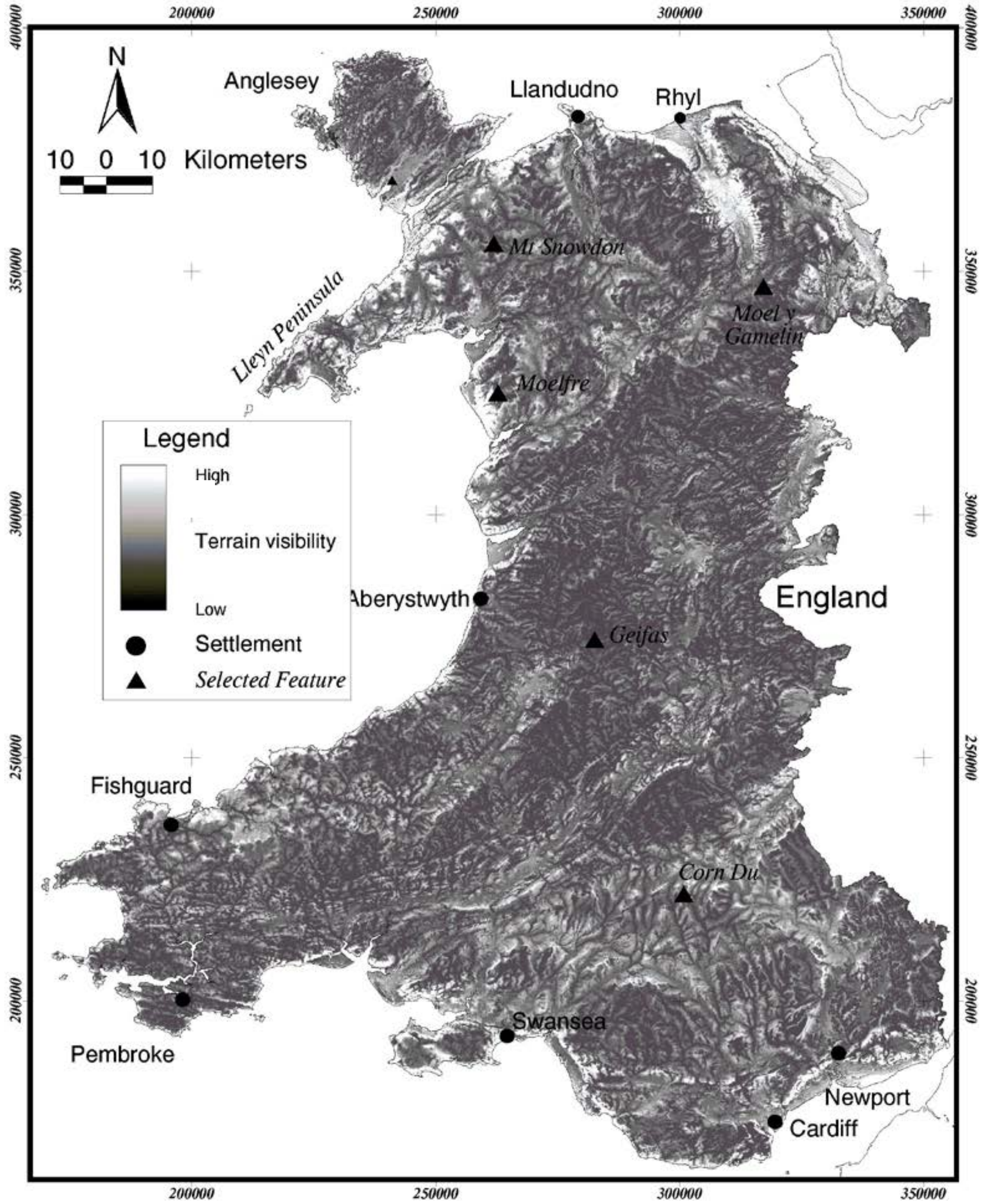


Figure 3 **Visibility of land, derived using a 10 km radius of view.**

3.2.1. Visibility of the sea from the land

The visibility of sea from the land was derived using the visibility census technique outlined in Section 3.2. For the analysis of the visibility of the sea a set of regular grid points at 1 km x 1 km intervals was derived for an area seaward of the coastline of Wales. These cells were used as inputs to the calculation of the relative visibility of the sea from the land, with the number of such grid points visible from each 50 m x 50 m cell to the landward side of the coastline, within a 10 km distance, making the score for that cell. Therefore, the grid points act as 'targets' for the calculation of views from the land. Figure 4 shows an example of the distribution of the regular grid of points in the coastal waters of west Wales used in the derivation of the visibility of the sea from the land.

The sensitivity of the extent of the visibility of the sea from different viewing distances was tested for an area in north-west Wales centred on the Lleyn peninsula. The viewing distances that were used were 5 km, 10 km and 15 km and 'no limit' (*i.e.* the distance constraint was removed). Two examples are shown in Figure 5.

Figure 5 shows the sample points at up to 10 km from the coastline, but the land from which the sea may be visible is calculated for a radius of view of 10 km (Figure 5 (a)), and 5 km (Figure 5 (b)). There are two significant differences between the two datasets.

1. The shorter 5 km radius results in less of the land area being highlighted as having views of the sea.
2. The shorter distance will result in fewer 1 km x 1 km sample points being within view and thus there is a lower potential level of visibility for any given location on land compared to that using a 10 km radius of view.

The calculation for the entire Welsh coast was finally undertaken with no distance limit applied, therefore, the views of the sea from the land would be from the theoretical maximum. The result of this analysis is presented in Section 4.4.1.

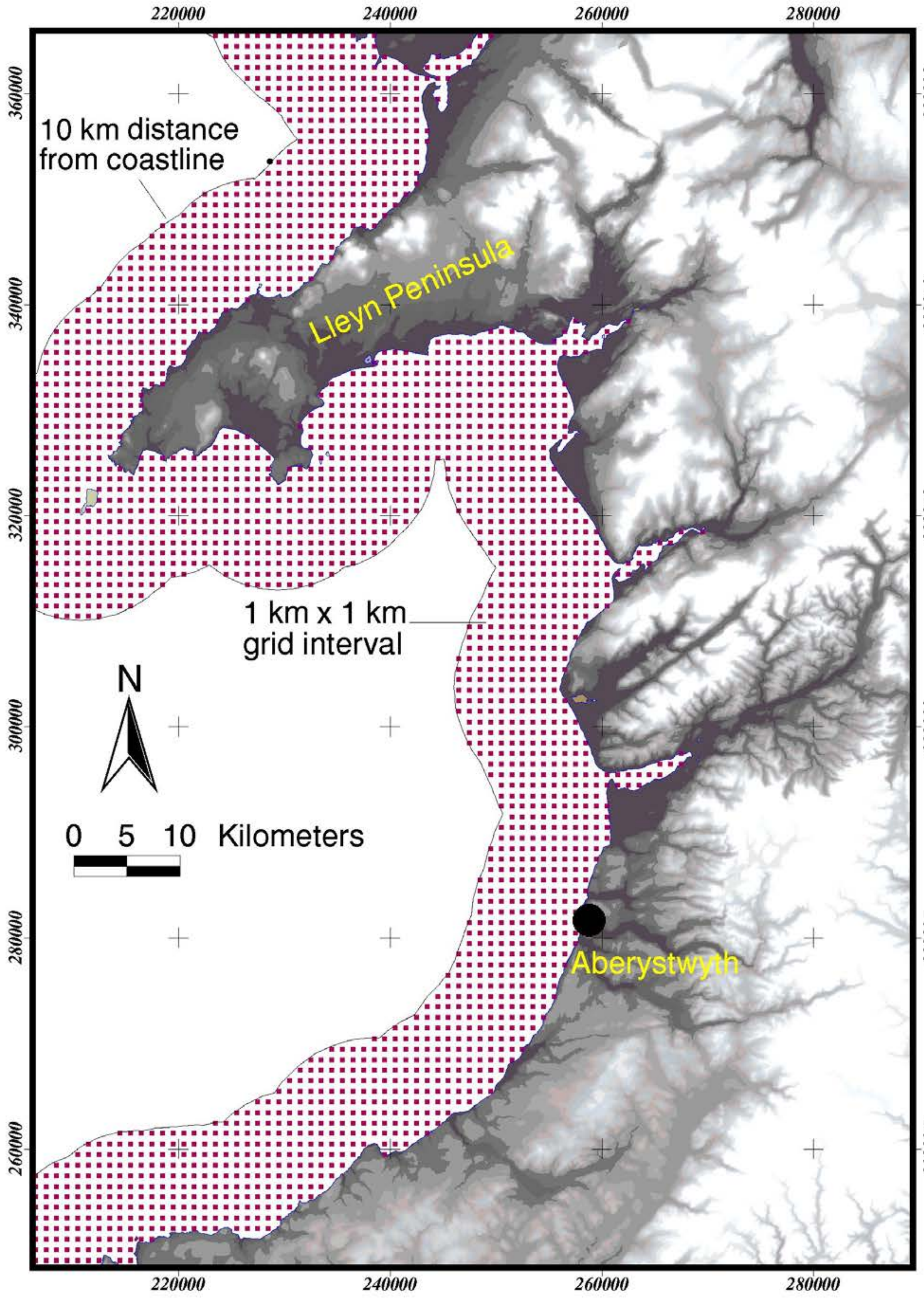
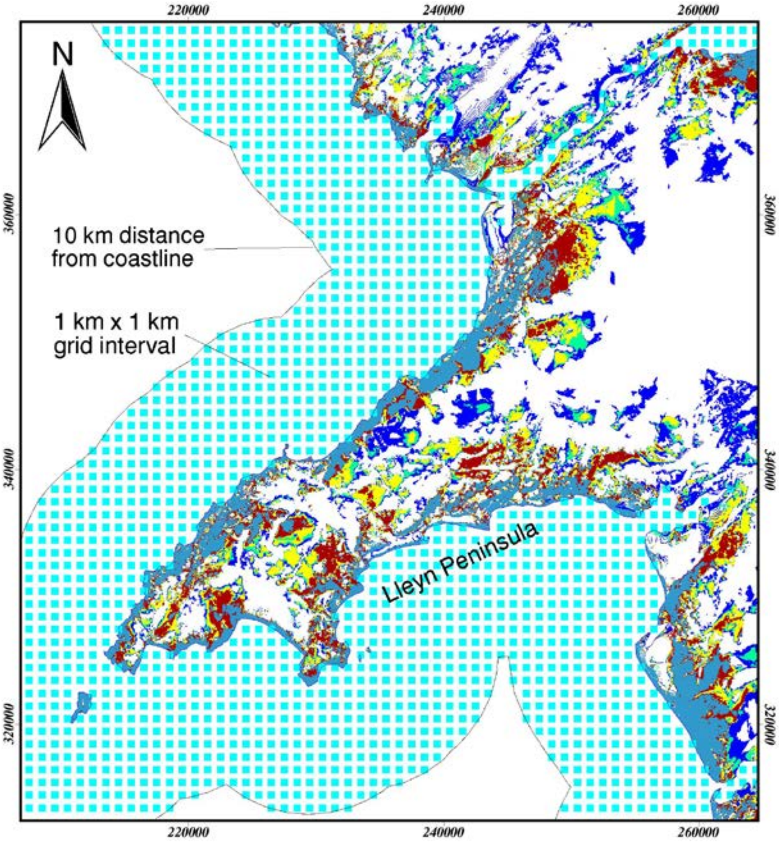


Figure 4 Example of the distribution of regular grid points at 1 km x 1 km intervals in coastal waters, up to a limit of 10 km from the coastline.

5 (a)



5 (b)

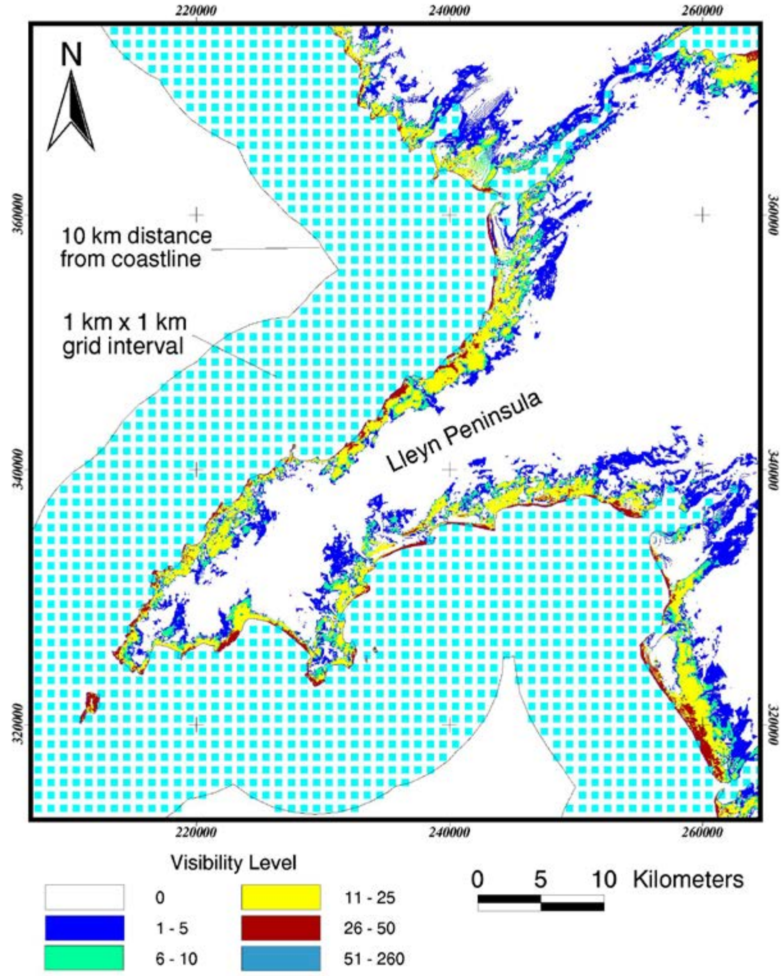


Figure 5 Examples of the differences in the extent of visibility of sea from land for the Lleyn Peninsula, using two different radii of view: (a) 10 km, (b) 5 km.

3.2.2. Visibility of land from the sea

The calculation of estimates of the visibility of the land from the sea is in recognition of the importance of features on land to the landscape views from the seaboard side of the coast, and the increased use of the coastal waters for transport, leisure (*e.g.* ferry traffic between Wales and the Republic of Ireland) and recreation (*e.g.* pleasure craft using the numerous harbours and marinas around the Welsh coast). More importantly, the output from this calculation also represents the identification of the land from which the sea is visible.

There are a number of options for the parameter settings for the derivation of visibility of the land from the sea. Exploratory calculations were carried out on the sensitivity of the extent of the land area to the distance of the radius of view which used radii of 5 km, 10 km and 15 km in the seaward direction.

The calculations were based upon a similar approach to that used in Section 4.4.1, *i.e.* a regular grid of points was derived at 1 km x 1 km intervals landward of the coastline. The DTM was analysed to determine the number of these points that were visible from each 50 m x 50 m land cell, the total of which provided the score for the relative visibility of the land from the sea.

Two options were then selected for the derivation of visibility of land from the sea for all of Wales:

1. A 10 km radius of view of coastal water up to 10 km out from the coastline.
2. No limit to the distance of view inland of coastal water up to 10 km out from the coastline.

These two options provide an indication of the maximum area of land from which features in the coastal waters closest to the coastline may be visible. Therefore, development in these coastal areas is likely to have an effect on the content (and possibly, the quality) of the view over the greatest area. The choice of the limit of 10 km was the estimated distance of view between an observer 1.8 m high at sea level and a small boat, estimated to be 1.25 m above water level (Table 1). However, it is recognised that a wide range of alternative values could be equally valid, and thus the selection is indicative of the approach that may be adopted, and modified to target more specific features. The results of these calculations are described in Section 4.2.

Figure 6 shows the distribution of points used as the input to the calculation. These points are in a 10 km band around the landward side of the coastline (Figure 6 (a)). Figure 6 (b) shows the output from the analysis for an area around the Lleyn Peninsula, in which the land is represented by the elevation model. The potential significance of obstructions to views of the land surface (*e.g* due to cliffs or small islands) on the derivation of the geographical distribution of the extent of the visibility of the land from the sea is illustrated. The consequence of such coastal features is apparent 'dead areas', from which other areas of land may not be visible.

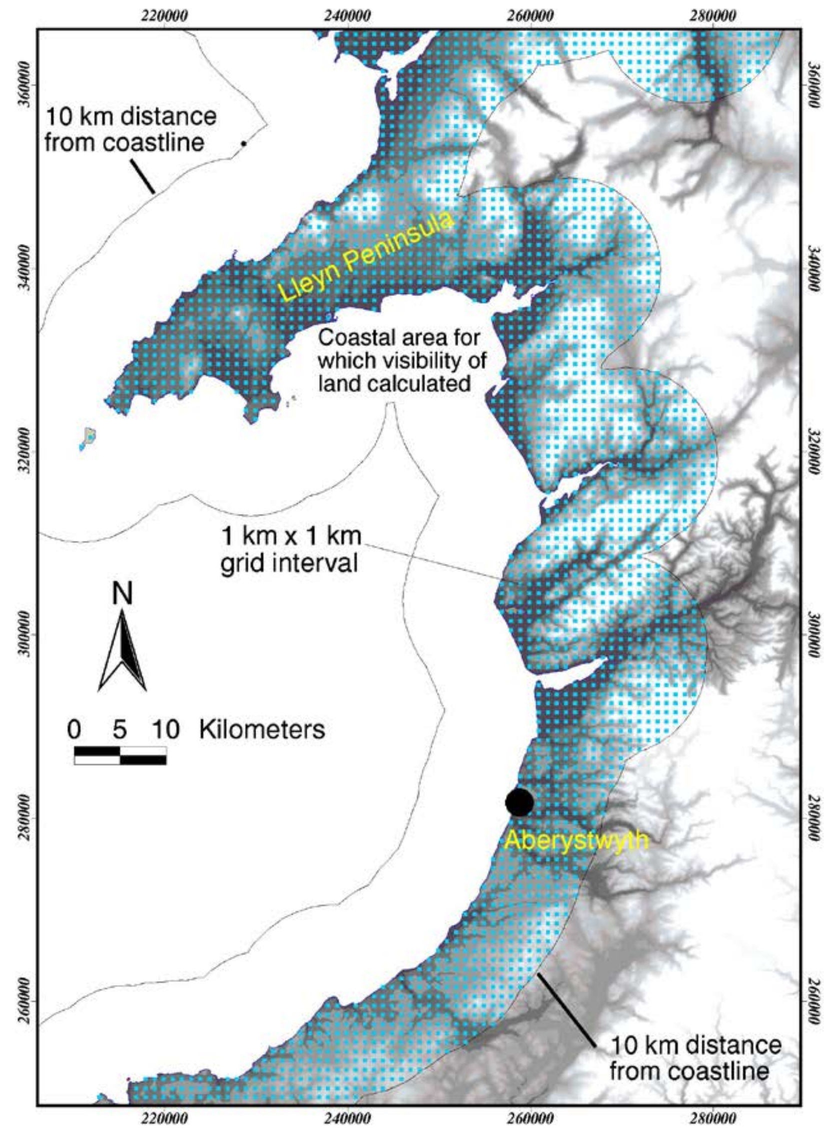


Figure 6 (a) Example of the distribution of regular grid points at 1 km x 1 km intervals, up to a 10 km distance landward of the coastline.

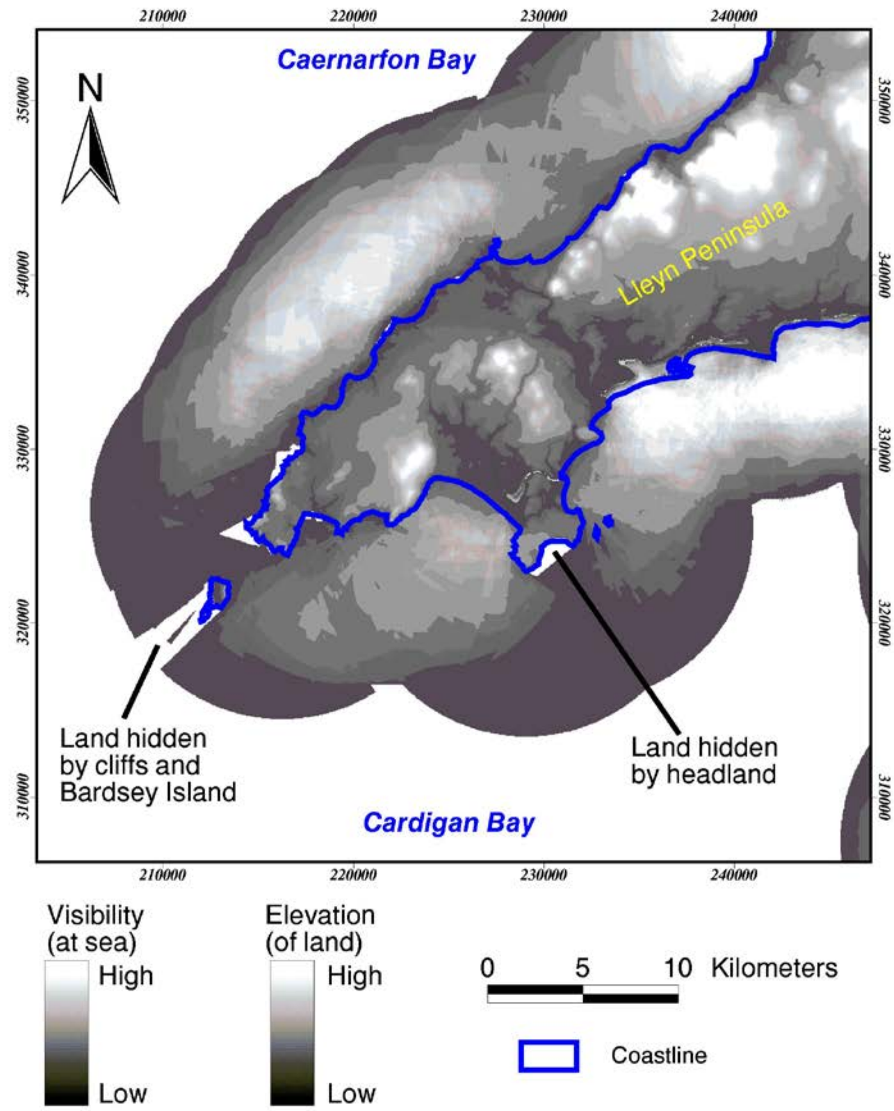


Figure 6 (b) Example of the output of the analysis of the visibility of land from sea, for the area around the Lleyn Peninsula. The land is represented by the model of elevation.

3.2.3 Vertical Dimension

The analyses presented in this report have all used a DTM dataset as the principal input. This dataset also enables the horizontal and vertical locations of points on land, or at sea to be used in the calculations of visibility. The outputs of each type of analysis are reported in terms of the number of cells, or the proportions of a horizontal plane that may be visible with regard to variations in the values of certain parameters, such as viewing distance.

The analyses presented thus far take no account of the proportion of the vertical view that may be occupied by either land or sea. For many coastal scenes consideration of the vertical dimension in the assessment and reporting of the visibility of land and sea will be necessary for future assessments of the distinctiveness of land and seascapes. There are two methods that may provide information to fill the gap in the analyses:

1. A visualization based approach, in which the surface area of the land visible is calculated for a sample of points at sea. To be consistent with the methods used in this report, such a sample could be at points on a 1 km x 1 km grid regular grid, with a viewing distance of 50 km.

2. A scoring approach, that uses a surrogate for the surface area which is visible, but one that is sensitive to the height of the terrain. Such a surrogate is use of the measure of the vertical angle from any point to the horizon.

The second approach has been adopted to test the segmentation of the area immediately offshore based upon the 'exposure' to the height of the terrain within view. The use of the summation of the angles to the horizon is based upon one which is widely used by the forestry industry in the assessment of topographic exposure. This measure is used in the calculation of the risk damage to trees due to wind (Bell *et al.*, 1995).

Within the context of seascapes, the sum of the vertical angle to the horizon in the eight cardinal directions of the compass has been used, from every 50 m x 50 m cell. The use of eight viewing directions samples the 360^{o} circle around a point (thus making the computation tractable in the time available), but leads to some artifacts in the geographic pattern around headlands, because the measurement of the angle to the landward horizon may be constrained to one direction. Examples of these artifacts are evident around Holyhead, the tip of the Lleyn Peninsula and St. David's Head.

3.2.4 Classification of coastal views

The importance of the presence of water in a scene is documented by a number of authors (Shafer and Bush, 1977; Wherrett, 1998). The derivation of a measure of relative visibility of the sea to views from the land provides quantitative data that can be used to identify where the most extensive sea views may be located. However, the output of that analysis does not provide information on the nature or structure of the view from each point along the coast (*e.g.* a narrow view framed between cliffs or hillsides, or an open view of the sea, with little or no framing).

There are a number of possible descriptors of the characteristics of the coastal views from a location. Among the physical characteristics of such views (as opposed to aesthetic, cultural or perceptual) are those listed below:

1. The proportion of the view that is occupied by water.
2. The horizontal extent of the view that water occupies (*i.e.* is the observer surrounded by water, or is it a view from the end of a narrow inlet?).
3. The vertical extent of the view of the water (*i.e.* is the observer looking down on the coastal view, or at sea level?).
4. The distance of the observer from the sea (*i.e.* are they looking from the coastline, or further inland?).

A characterization of coastal views was derived which addresses some of the four descriptors noted above. The objective was to identify which parts of the coast have more open or closed views of the coastal waters. The proportion of the view that is occupied by water is addressed in Section 3.2.1, and the contribution of the vertical angle between the observer and the coastline was discussed in Section 3.2.3. The approach developed in this section addresses the extent of the horizontal view that is occupied by water.

The method quantifies the proportion of the width of the view which would be occupied by the sea. The direct measure of width would be the horizontal angle that subtends the area of a view occupied by the sea. However, any one view point could have a number of sea views, interrupted by promontories of land. Rather than attempt to store information about different sea views from the same point, surrogate measures were adopted. These surrogates were:

1. The proportion of the circumference around a view point that is occupied by water. Each measure was made for two radii: 6 km and 10 km. The 6 km radius is consistent

with the distance to the horizon at sea level (Table 1) and 10 km maintains the standard viewing radius across all of the analyses.

2. The length of coastline which is visible within the 6 km and 10 km radii.

A key difference between this analysis and that of the previous two sections was that it was based upon visibility calculations made for points in a band around the coast within which the horizontal extent of sea views may be considered to be most significant, compared to views from higher land, which would predominantly be downward-looking and open. The observation points selected for this analysis comprised a 1 km x 1 km regular grid up to 5 km from the coast. This ensured that, even from relatively level land, the coastline would be within the distance to the horizon of any point.

For observers close to the coastline, the horizontal extent of sea views would be substantially greater, but the resolution of the input data may become a more significant issue. In level coastal areas, the significance of surface features such as woodland, individual trees and buildings may contribute more to the framing, or constraints of the horizontal extent of a view than views from locations further inland.

The procedure for creating the classification of sea views is summarized below:

1. A set of points is created for land within 5 km of the coast at intervals of 1 km x 1 km.
2. The land visible from each point is calculated.
3. Two distance buffers are derived for each point, at 6 km and 10 km radius.
4. Four values are calculated –
    a) the length of coastline visible from each point within 6 km;
    b) the length of coastline visible from each point within 10 km;
    c) the proportion of the circumference of a circle of 6 km radius that is both visible and intersects with sea water;
    d) the proportion of the circumference of a circle of 10 km radius that is both visible and intersects with sea water.

Figure 7 shows the visibility derived for an example point on the Lleyn Peninsula and the two distance buffers at 6 km and 10 km.

The outputs from this analysis have been classified into a five class scheme which is designed to be sensitive to small values and is progressively less sensitive to variation in larger values. The use of five classes is a compromise between simplifying the presentation of the results and retaining a degree of detail within the illustrations.

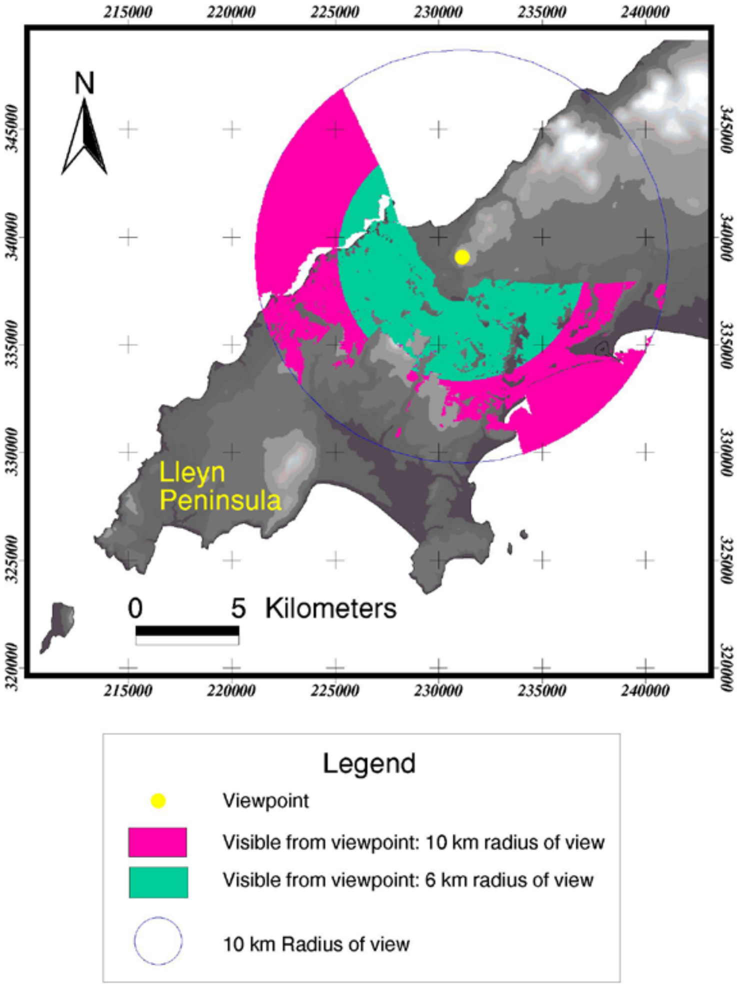


Figure 7 Derivation of classification of coastal views: combining visibility calculation and distance from the observer.

4. Results

The outputs from the analyses of visibility are described below for each of the three types of analyses.

4.1. *Visibility of sea from the land*

4.1.1 Results

The land from which the most extensive views of the sea are available is predominantly around the north and west coast (excluding Anglesey), extending from approximately Llandudno, west along the Lleyn peninsula south towards Aberystwyth and Fishguard. The coastline in the vicinity of Swansea also offers sites of high visibility of the sea, but the south-west coastal area, around Pembroke has few extensive sea views inland from the coast.

The pattern of views of the sea from the land largely reflects the adjacency of higher land, with west facing hill and mountain slopes, with the coastline. Table 2 shows the distribution of the visibility of the sea with the altitude of all land in Wales, and Table 3 shows the distribution with respect to the aspect of all land in Wales.

Table 2 Areas of visibility levels with respect to elevation (km^2).

	Elevation (m)						
Visibility Level	**0 – 10**	**11 – 25**	**26 – 50**	**51 – 100**	**101 – 500**	**> 501**	**Total**
0	513	1 607	2 422	6 104	6 319	650	**17 616**
1 – 25	284	209	175	225	140	33	**1 066**
26 – 100	79	162	162	203	118	33	**762**
101 – 500	14	256	256	374	195	53	**1 060**
>501	< 1	26	26	113	102	48	**292**
Total	**890**	**2 261**	**3 042**	**7 019**	**6 874**	**817**	**20 795**

Table 3 Areas of visibility levels with respect to aspect (km^2).

	Aspect									
Visibility level	**'Level'**	**North**	**North-east**	**East**	**South-east**	**South**	**South-west**	**West**	**North-west**	**Total**
0	322	2 083	2 078	2 101	2 609	2 290	2 026	1 836	2 271	**17 616**
1 – 25	85	101	88	85	139	147	143	129	149	**1 066**
26 – 100	8	85	65	52	90	112	120	110	120	**762**
101 – 500	< 1	138	87	56	95	149	160	169	205	**1 060**
>501	< 1	44	16	5	10	28	45	64	80	**292**
Total	**417**	**2 451**	**2 334**	**2 299**	**2 943**	**2 726**	**2 493**	**2 308**	**2 825**	**20 796**

The results from Table 2 and Figure 8 show that the majority of the land that lies on the low-lying areas of the coastal estuaries and sand flats offer the lowest extents of sea visibility, but also that some of the land less than 10 m above sea level has views of the water, as measured by the number of 1 km x 1 km sample points used in the analyses. Locations with this level of sea visibility include the south-east of Newport, Pembury and the Pendine Sands, Cors Fochno on the south side of the River Dovey Estuary, Malltraeth Bay on Anglesey and the area around Rhyl on the north coast.

At the highest elevation band (500 m and above) the areas of each band of visibility of the sea are relatively evenly distributed, ranging between 33 km^2 (for the lowest level of visibility of the sea) and 48 km^2 (for the highest level of visibility of the sea). These figures reflect the different topographic forms at higher elevations, including the more rolling hill tops of some parts of the Brecon Beacons (from which the views of the sea within 10 km of the coastline may be restricted due to the plateau tops), compared to the more heavily glaciated shapes of the Snowdonian Mountains, from which more coastal water is visible.

The distribution of the visibility of the sea from the land with respect to the aspect of the terrain shows that the higher visibility levels (*i.e.* visibility level greater than 100) are most extensive in a western arc between south-west and north-west. This largely reflects the distribution of the coastal area of Wales, with relatively few views looking in an eastern direction.

The coastal waters within 10 km of the coastline are calculated to be visible up to approximately 40 km inland at Corn Du in the Brecon Beacons National Park, and also from places such as Moel y Gamelin in Denbighshire (26 km), Geifas in Ceredigion (24 km) and Carmarthen Ven in Carmarthenshire (31 km).

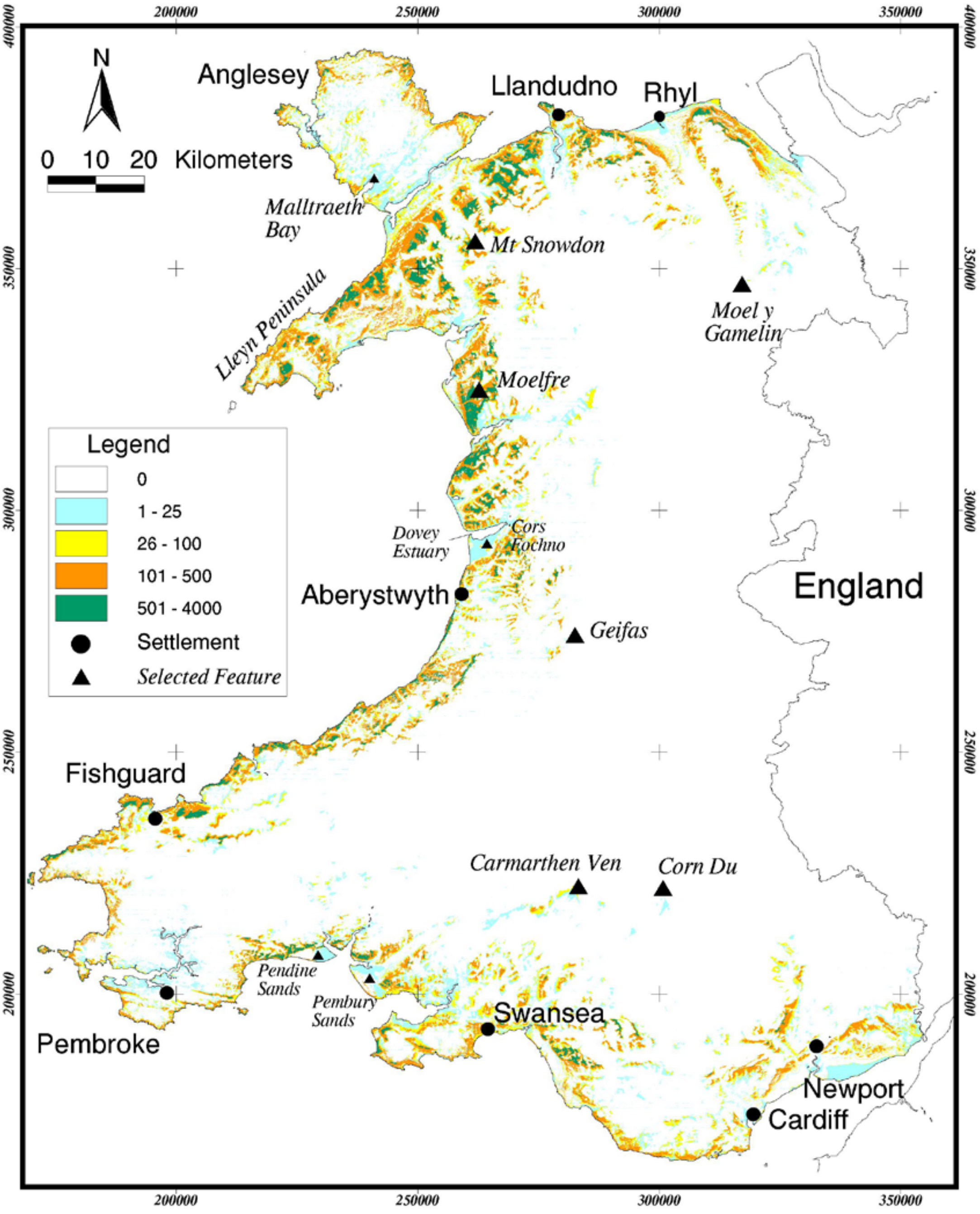


Figure 8 **Geographical distribution of the visibility of the sea from the land.**

4.1.2 Future developments

1. A consequence of using a DTM at a resolution of 50 m x 50 m (*i.e.* medium to low resolution) may be to limit the calculation of the visibility of the sea from some points that are close to the coast, but in surrounding land that is level. The effect of this would be to underestimate the visibility in some areas, although the impact may be offset by the absence of consideration of any surface vegetation.

2. Although the land that lies near sea-level around the coast offers views with a relatively small extent of the sea, such areas will be affected by structures built offshore. At, or near, sea-level structures within the field of view (*i.e.* close enough to the coastline to be visible above the horizon) are likely to be perpendicular to the horizon, whereas, locations from which a greater extent of the sea may be visible (*e.g.* land locations several hundred metres above sea level) may be looking downwards on built structures at such an angle for them not to be profiled against the horizon.

Therefore, a greater extent of a sea view at a location will increase the likelihood of offshore features being in view, but it does not imply that the impact of a feature on the viewer is also greater.

3. The use of the visibility scores requires further refinement to enable the selection of standard thresholds. This will improve the quality of the comparisons, and the interpretations that may be made between different analyses.

4. The area of land close to sea level from where there appear to be few, or no, views of the sea is likely to be overestimated for two reasons:

- i) The calculation of visibility is most sensitive to minor errors in the DTM in areas that are level, because the effect of such an error would be to obscure the view of an observer at a small viewing height.
- ii) The sample of points used in the approach adopted is 1 km x 1 km apart. Therefore, there are likely to be a number of coastal locations from which the sea would be visible, but none of the sample points, due to the shape of the coastline, or intervening terrain. This limitation can be reduced by using a denser sampling pattern, but with the cost of significantly higher processing time and overheads.

Future work could include a test of the sensitivity of the visibility analyses to different densities of sample points, to estimate how much this factor may influence the pattern of visibility shown in Figure 8.

4.2. Visibility of land from the sea

4.2.1 Results

Figure 9 shows the results of the calculation of the visibility of the land from the sea, within a 10 km radius of view, with the areas from which most land may be visible, and those areas from which least land may be visible can be interpreted. The analysis has been constrained to the inshore area of the coastline, with a maximum of a 10 km radius of view. This analysis calculates the number of 1 km x 1 km points 'on land' that may be visible from each 50 m x 50 m cell seaward of the coastline, up to a maximum distance of 10 km.

The areas from which most land is recorded as being visible from the sea are the following:

1. In concave stretches of coastline. *i.e.* in bays, such as Swansea Bay or the Tremadog Bay.
2. Between headings or coastal features, such as Burry Inlet and the Dee Esturary.
3. In the eastern stretch of the Bristol Channel.
4. In the approaches to the Menai Straits, where the width of the water feature is approximately 7 km at the widest point, and from which the high land in the northern part of the Snowdonia National Park is visible.

Sections of the offshore areas from which the coastal land is less visible are where the coastline is almost linear or convex:

1. The southern coast of Cardigan Bay between Fishguard and Aberystwyth, which includes the Ceridigion Heritage Coast.
2. The stretches of coastline south of the Gower Peninsula.
3. The coastal area off of the South Pembrokeshire Heritage Coast.
4. The coastal waters south-west of Anglesey.

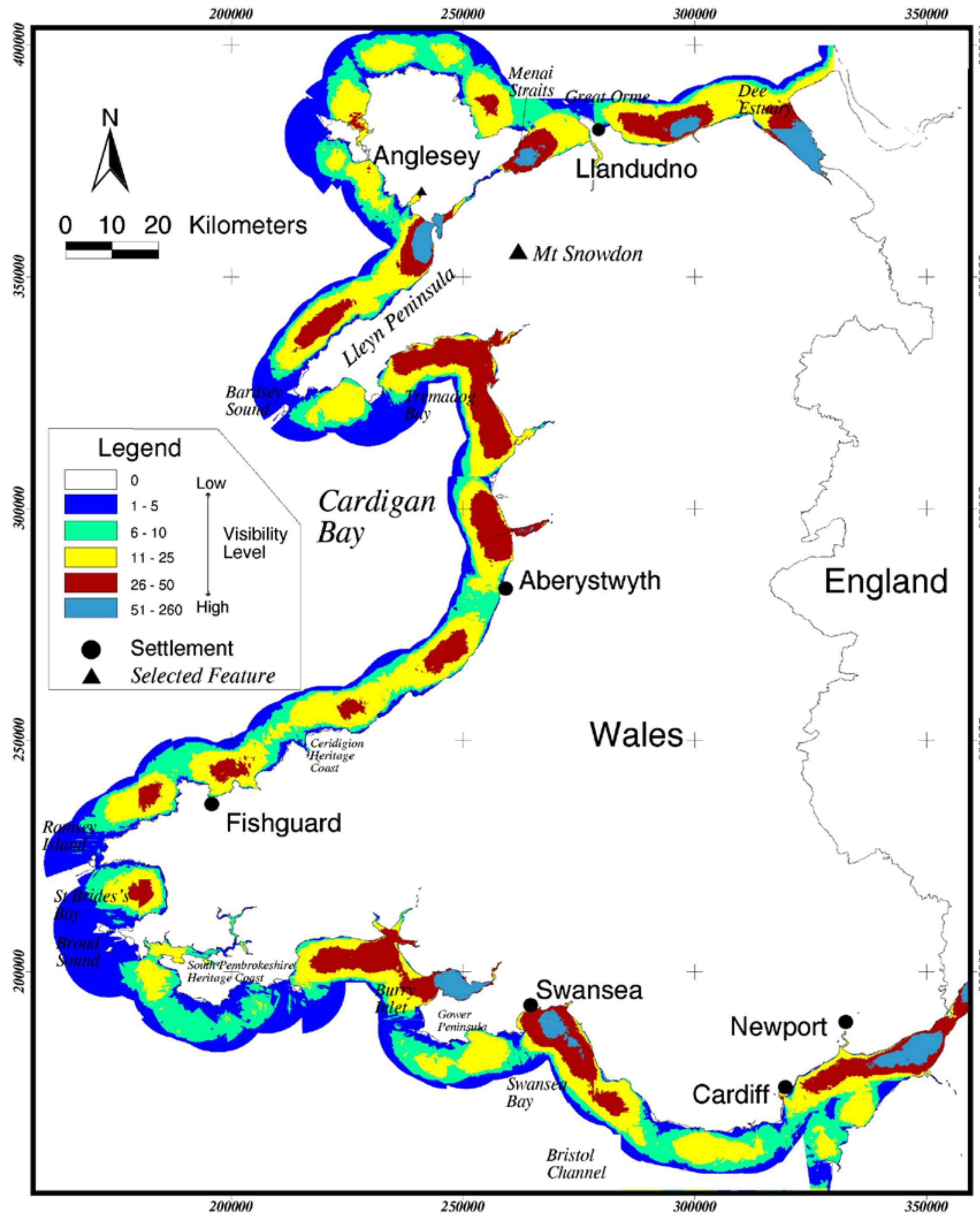


Figure 9 Geographical distribution of the visibility of the land from the sea.

An exception to this pattern is the north-west coast of the Lleyn Peninsula, where the coastline is convex, but land up to 370 m in height is within 5 km of the coastline and clearly visible.

The lowest scores are recorded off the tips of headlands and peninsulas. Most evident amongst these are:

1. Bardsey Sound at the end of the Lleyn Peninsula;
2. the Great Orme at Llandudno;
3. Ramsey Island near St. David's and, to a lesser extent, Broad Sound on the south side of St. Brides Bay;
4. Rossili Bay at the west end of the Gower Peninsula.

Low levels of visibility of land from sea are also recorded where the closest land is low lying and the higher land is beyond 10 km, such as off the Glamorgan Heritage Coast south of Bridgend and offshore of Prestatyn on the north coast.

4.2.2 Future development

1. The use of a 10 km radius for this analysis constrains the results to a relatively narrow band of the area offshore of the coastline. It removes consideration of the visibility of some of the higher land, from which the sea was shown to be visible in Section 4.1.

2. The visibility of points on-land from the sea will be limited where there are areas of the coastline that are cliffs, as mentioned above. Therefore, this analysis cannot be interpreted in terms of its potential high or low sensitivity to impacts of changes in use of the offshore environment. This is because areas of coastline that are sea cliffs may be considered to be of a high landscape value (Wherrett, 1998), but the area immediately offshore may have a low score.

3. An analysis of only the visibility of the land from the sea takes no account of the contribution made by the surrounding water to views.

This analysis could be improved by incorporating a greater viewing distance, and including an assessment of the visibility of the surrounding area of water that is visible.

However, the analysis does provide an indication of the visibility of the land from the sea, but may be used more usefully as a further basis for the interpretation of the sea from the land, in that:

i) it highlights where at sea is least visible from the land (*e.g.* the seaward side of cliffs);
ii) it highlights the areas of water closest to the land (*i.e.* at a 10 km distance and less) that will be visible from points on-land.

Therefore, the effects on the views from locations within 10 km of the coast will be greatest where use is made of offshore areas where the score is highest, which are:
the Dee Estuary, Rhyl, the approaches to the Menai Straits, Burry Inlet, Swansea Bay and the eastern stretch of the Bristol Channel.

The analyses reported in this section and Section 4.1 were based upon a separation of the coastal zone between land and sea. However, in the inter-tidal zone is wide in many areas of sands and mud-flats. Further, an observer's understanding of 'the coast' is not necessarily constrained to the coastline as mapped. Therefore, a trial analysis was also carried out on the intervisibility of the coastal area. In this trial, the sample points used in the visibility analyses were in a regular grid pattern at 1 km x 1 km intervals in a band 10 km either side of the mapped coastline but similar geographic areas were identified as being of high visibility (*e.g.* in the vicinity of the Menai Straits).

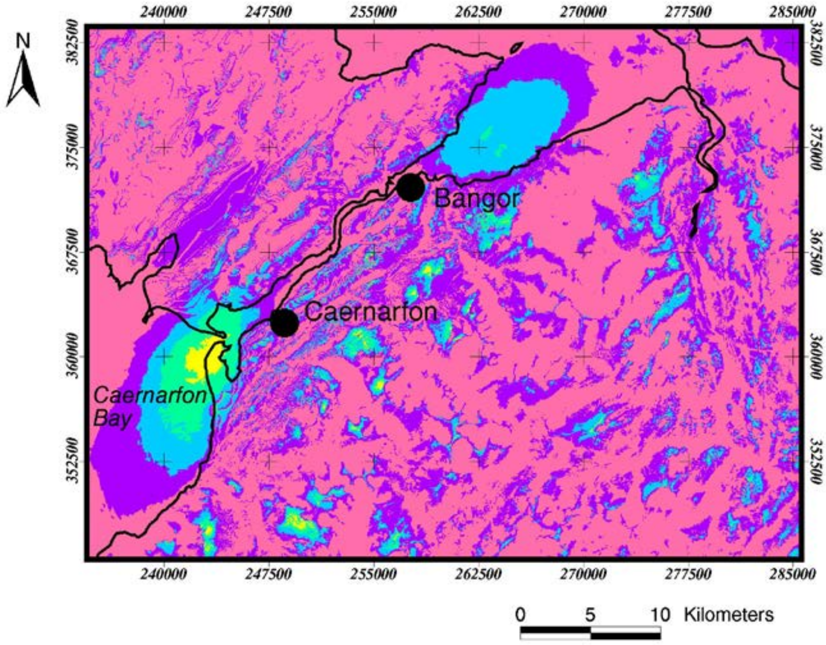
From Figure 10 a more comprehensive impression can be gained of the intervisibility of the coastal zone. Figure 10 (a) shows the results the 1 km x 1 km sample points for the land area are used to derive the visibility of both land and sea, and Figure 10 (b) shows the output when sample points have been used distributed across land and sea. In the latter example, the scores are higher due to the larger number of potential target points from land and sea.

4.3 Vertical dimension

4.3.1 Results

Figure 11 shows the output of the analysis. The calculation has been limited to points within a 10 km distance to the seaward side of the coastline, but a 40 km radius of view has been used, based upon the maximum viewing distance recorded in the derivation of the results in Section 4.1. The results to the south, south-east and north-east of Wales include the effect of the angles to the horizon of terrain in England.

(a)



(b)

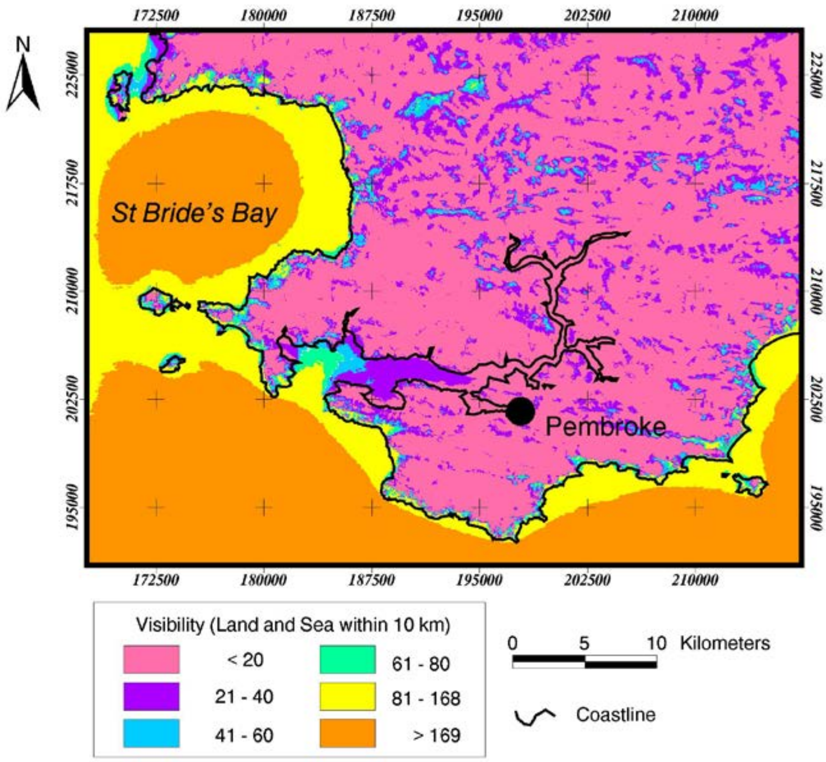


Figure 10 Intervisibility of the land and sea. (a) Derived from a 1 km grid of 'target points' on land, but results produced for both land and sea. (b) Derived from a 1 km grid of 'target points' across land and sea, and results produced for both land and sea.

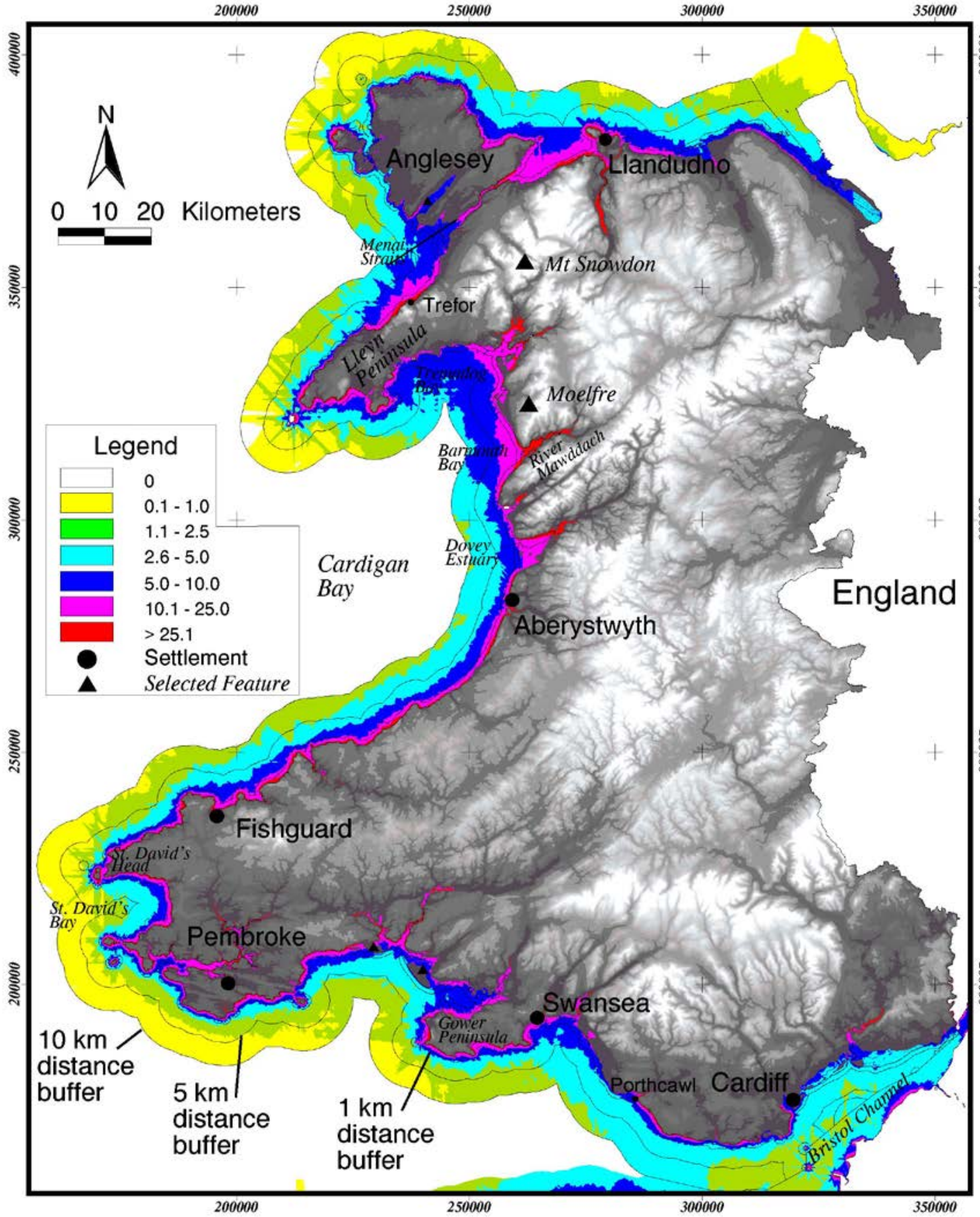


Figure 11 Geographical distribution of the effects of terrain height on views from the sea.

Table 4 The range of vertical angle scores for three different distances seaward from the coastline: 0 to 1 km, 1 km to 5 km, and 5 km to 10 km (values in km^2).

Distance	Vertical Angle (^{o})							Total
	0	0.1 to 1.0	1.1 to 2.5	2.6 to 5.0	5.1 to 10.0	10.1 to 25.0	25.1 to 90	
1 km	0	<1	10	147	389	458	5	**1 010**
5 km	1	149	584	1 367	811	159	<1	**3 071**
10 km	45	683	1 124	932	141	0	0	**2 925**
Total	**46**	**833**	**1 718**	**2 446**	**1 341**	**617**	**5**	**7 006**

Table 4 shows a total of just over 7 000 km^2 of coastal waters up to 10 km from the coastline of Wales. Of this area approximately 1000 km^2 is within 1 km of the coast. It is within this band that the steepest vertical angles to the horizon have been measured, reflecting the impacts of the close proximity to cliffs in areas such as parts of the Pembrokeshire coast or the Lleyn Peninsula south of Trefor, and the higher angles to the horizon due to the elevation of the terrain landward of the coastline. One other area where the highest values (greater than 25^o) were obtained was within estuaries or river mouths such as Barmouth and the River Mawddach.

The most extensive areas of high values of the sum of vertical angles (those greater than 10^o) are in Tremadog Bay, Barmouth Bay and the eastern approaches to the Menai Straits. These areas are also extensive within 5 km of the coastline, with approximately 158 km^2 of coastal waters having such scores, predominantly in Barmouth Bay and the eastern approach to the Menai Straits.

The effect of the higher elevation of the landward side of the coastline is also evident around Cardigan Bay. Around St. David's Bay the most extensive area is that of angles greater than 2.5^o, with maxima above 10^o close to the shoreline. Off St. David's Head, the values drop such that the most extensive area has values in the range 0.1^o to 1.0^o, reflecting the relatively low proportion of terrain at high elevations. However, in the vicinity of Fishguard, 25 km further north, the elevation of the terrain has a greater impact, with vertical angles of greater than 2.5^o becoming predominant. Offshore of Aberystwyth the vertical angles are almost all above 5^o as the impact of the visibility of higher land, such as the southern end of the Snowdonia Mountains, becomes measurable.

Similarly, for the coast off Porthcawl and in the eastern stretch of the Bristol Channel, the effect of the elevation of the land increases, producing vertical angles of up to 50^o. The effect increases further as the Bristol Channel narrows towards the Mouth of the Severn.

The areas on which the elevation of the terrain would appear to contribute the least to the view contents are in a band between 5 km to 10 km off the south-west coast of Wales, stretching from approximately the Gower Peninsula to St. David's Head. In these areas, the sum of the vertical angles is less than 1^{o}. Similar areas which have fewer views of higher elevation land are off the west and north coasts of Anglesey and the south-western tip of the Lleyn Peninsula.

4.3.2 Future development

The derivation of a score that reflects the extent of the height of the surrounding land on a point is sensitive to several elements of the input data and, potentially, the method of computing the score. These are summarised below:

1. The main source of data used is the DTM, the scale and resolution of which will influence the accuracy of the vertical angle derived for a point. In general, the use of small scales of input data, or low resolution raster data, will result in the underestimation of vertical angles (Jones, 1998). The Ordnance Survey 1:50 000 maps and the 50 m x 50 m resolution Panorama DTM (Ordnance Survey, 1996) derived from them will be restricted in the level of elevation detail that can be represented, compared to that from larger scales such as 1:10 000. The effect will be greatest where there are changes in elevation over very short horizontal distances, such as coastal cliffs. Therefore, the angles derived close to such clifflines will very likely be underestimates.

   This may not impact significantly on the interpretation of the geographic distribution of the vertical angles scores, particularly when considering a strategic view of all of the Welsh coastline. However it may be relevant if a detailed study was being conducted at a site level.

2. The derivation of the vertical angle from a raster dataset involves a number of different assumptions, which may impact upon the output. For example, data with a resolution of 50 m x 50 m represents each entire cell with a single height value. The calculation of the vertical angle has been from the centre of the cell of the observer to the centre of the cell that represents the terrain at the horizon. Alternative approaches include those that take account of the terrain surrounding each cell and calculate the vertical angle base upon mathematical models of the shape of the topography (Jones, 1998). In general, such algorithms are not directly implemented in the most

commonly used GIS packages although it may be valuable to test the sensitivity of the output with respect to the type of algorithm used, particularly for site level studies.

3. Further processing would be required to extend this analysis to the entire coastal zone of Wales, at a greater radius of view, and for a wider area than that confined to the 10 km band around the coastline. The analyses of sea from land, and land from sea, could be 'intersected' at the coastline, and used in combination with land use data to identify the maximum area either side of the coastline for which the intervisibility analyses may be undertaken. The output of this analyses could then be used in conjunction with the land use data as inputs to assessing the importance of land use features in the visual landscape.

4.4 Classification of coastal views

4.4.1 Results

Figure 12 to Figure 14 show the classification of coastal views using three different measures for each 1 km x 1 km point within 5 km landward of the coastline:

1. the horizontal extent of coastal views within 10 km of the observer;
2. the horizontal extent of coastal views within 6 km of the observer;
3. the length of coastline that is visible within 10 km of the observer.

The results in Figure 12 show that the views with the lowest proportion of water within a 10 km radius are, broadly, in three types of location:

1. low-lying land which is in the vicinity of the coastline (*e.g.* Pendine Sands and Penbury Sands);
2. land close to the sea, but on a coastal plateau or on 'flat-topped' hills, such as the Gower peninsula and the area around Pembroke;
3. river valleys and valley sides furthest from the coast (*e.g.* River Conwy, River Towy, River Mawddach and the River Dovey).

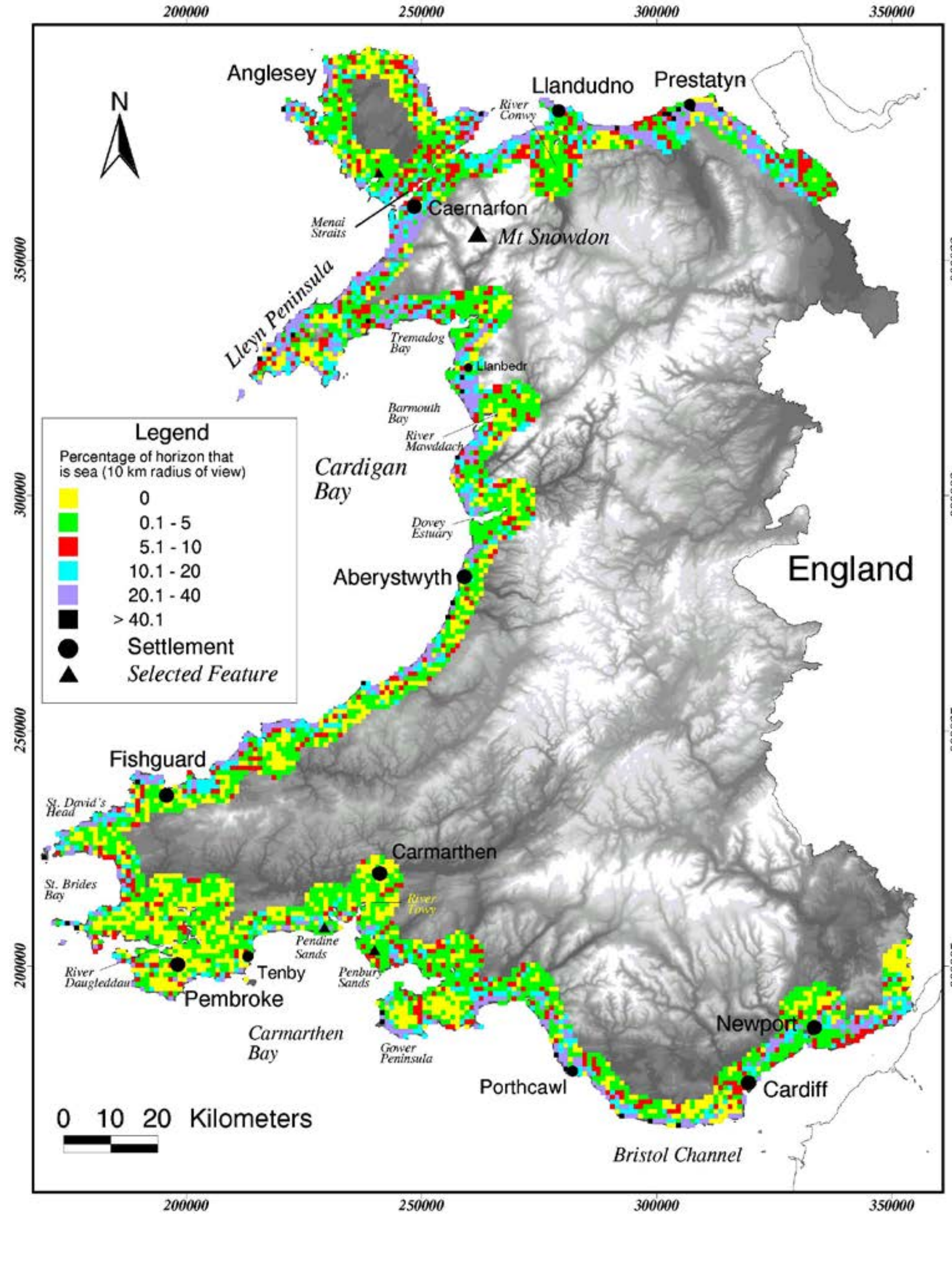


Figure 12 Extent of horizontal view occupied by the sea at a 10 km distance, as measured by the proportion of the horizon for which the sea is visible.

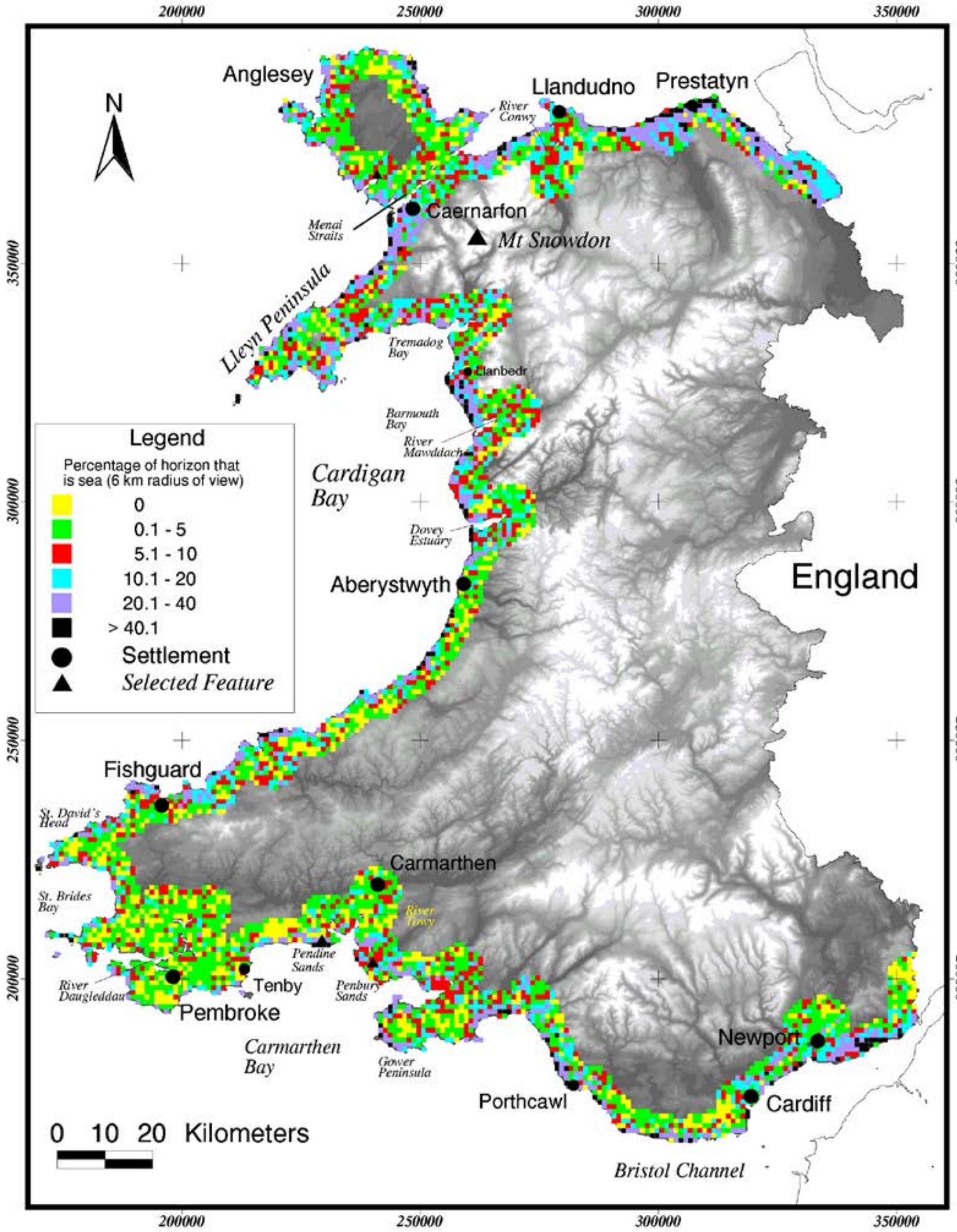


Figure 13 Extent of horizontal view occupied by the sea at a 6 km distance, as measured by the proportion of the horizon for which the sea is visible.

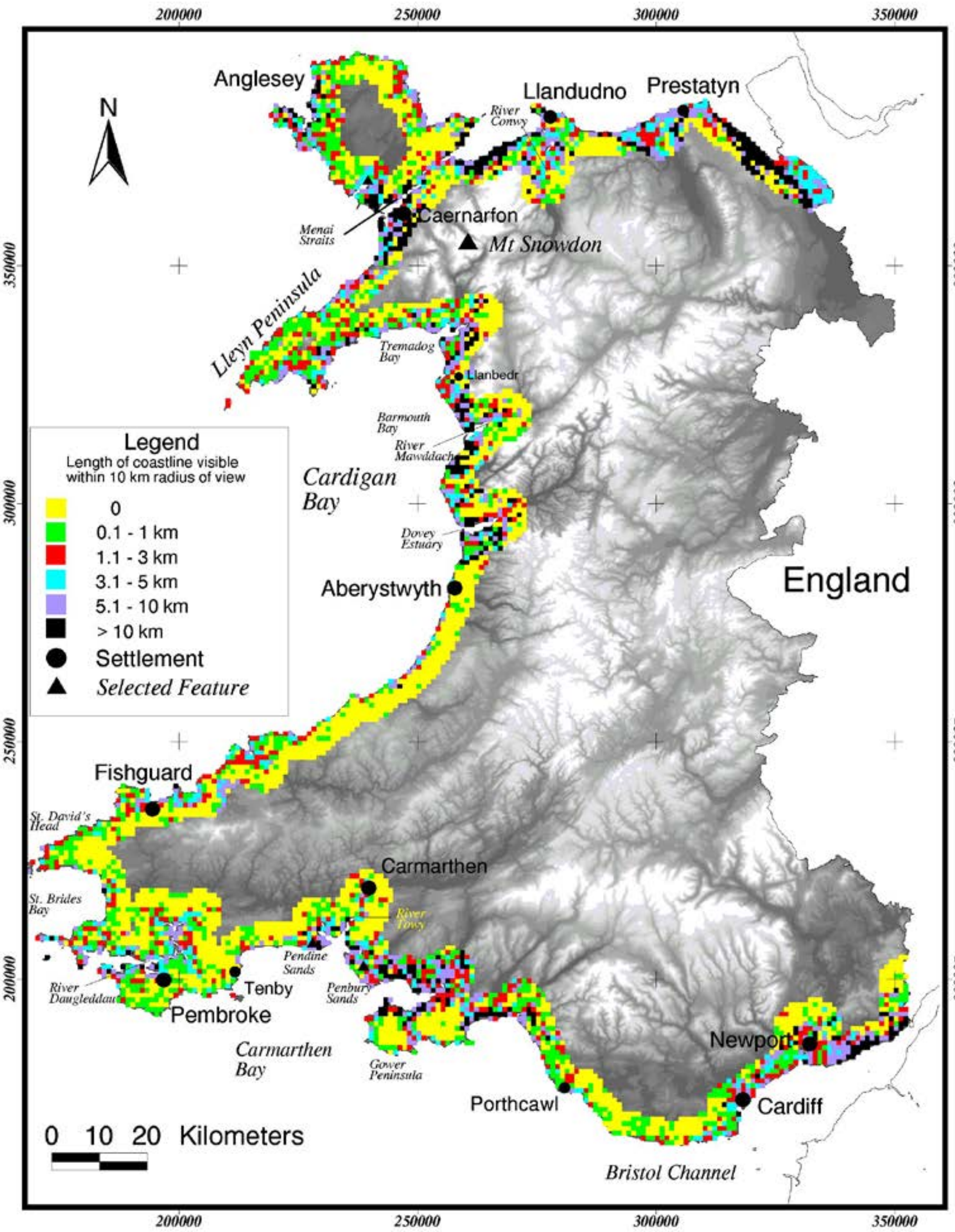


Figure 14 **Length of coastline visible within a 10 km radius of view.**

Figure 12 shows that the highest proportions of visible water are those above 20%, which are predominantly from points within 1 km of the coastline on land that slopes towards the water, although areas such as that south of Caernarfon, south of Llanbedr or in the vicinity of Prestatyn all enable similar levels of sea views up to 5 km inland. Other locations with high percentages of water visible include the east coast of Anglesey, locations on the north coast of the Lleyn Peninsula, in the vicinity of Fishguard, and sections of the south coast around the Gower Penionsula and Porthcawl.

Very low proportions of the horizon, at a 10 km radius of view, are occupied by sea in land around Pembroke, and the landward end of river valleys such as the Towy. The low levels of visibility of the sea using this measure is largely due to the low lying nature of the topography combined with the distance from areas of open water. The inclusion of such areas in the analysis is due to the definition of the coastline as represented in the OS Land Line dataset.

The proportion of the coastal waters that are within 6 km of the observer (Figure 13), rather than 10 km, shows a broadly similar pattern in the geographic distribution of the classification of views. However, because the radius of view is smaller, it is more sensitive to the extent of sea that is visible and the use of the 6 km radius of view emphasizes those areas for which the sea occupies the highest proportions of the horizontal view. These areas are around Prestatyn, the east coast of Anglesey, Caernarfon, south of Llanbedr and sections along the southern coast of Cardigan Bay, and the south coast around the Gower Peninsula. The change in radius of view has also excluded the contribution of land between 6 km and 10 km from the observer which could have had the effect of constraining the measured extent of sea at the horizon, therefore increasing the extent of the sea at the 6km distance. This effect is apparent along the coast to the east of Newport.

Obviously, the use of a smaller radius will also result in a reduction in the proportion of water in the locations furthest from the coastline, but there are a number of locations in the immediate vicinity of the coastline from which there are also very constrained, or no views of the sea at the 6 km distance. The latter case will be predominantly due to the effects of local topography (*e.g.* shielding the view) on the calculation of visibility, as the basis of the analyses is cells 50 m x 50 m in resolution sampled at 1 km x 1 km intervals.

The length of coastline visible within 10 km from each sample point (Figure 14) provides a basis for assessing the complexity of the coastline in certain areas. Similar to the pattern of the proportions of water visible, the length of coastline that is visible is generally further inland along a river valleys (*e.g.* River Towy and River Conwy). However, one exception with regard to the length of coastline is the area around the River Daugleddau in Pembrokeshire, which has been retained as ‘coastal’. The close proximity of the two sides of the river (although over 500 m wide in places), and its meandering course inland has resulted in the land around it being highlighted in the analyses of coastline as an area of high coastline visibility.

In general there are another five areas from which the longest stretches of coastline may be visible. These are:

1. The coast to the east of Prestatyn, where the west coast of the Wirral, in England, contributes to the high score, and the slopes towards the coastline are open, with no lines of cliffs.
2. The approaches to the Menai Straits, including Llandudno, where the coastline around the Straits are sufficiently close, as to contribute to a high score.
3. The north-east of Cardigan Bay, where there are open views of the coastline from land that rises in elevation rapidly inland of the coast. (The coastal waters in this area were highlighted in Section 4.3 as an area from which the vertical dimension of the terrain could make a significant contribution to views.from offshore).
4. The east side of Carmarthen Bay, where the coastline of the Gower Peninsula and that of the Penbury Sands to the north are in close proximity. However, the cliffs on the north side of the Gower Peninsula limit the views of the coastline.
5. The land to the east of Newport, where the coast of England contributes to the higher scores, and the coastline is open to views from further inland.

The land from which the shortest lengths of coastline may be visible are where there are dramatic changes in height close to the coast (*e.g*. where there are lines of cliffs) and shallow sloping terrain inland. This pattern is most pronounced along the southern edge of Cardigan Bay, where only those locations closest to the coast will have extensive views of the coastline. The pattern of small headlands around this part of the coast will probably restrict views of long stretches of coastline within a 10 km radius of view. Other areas from which the lowest proportions of coastline are visible are the inland reaches of rivers such as the Conwy and Dovey; and low-lying, convex stretches of coast, such as that around Porthcawl.

4.4.2 Future development

The results in the analysis of the classification of coastal scenes will be sensitive to the scale of the input data (both DTM and coastline) and the intensity of the sample points (1 km x 1 km), which are also discussed in Sections 4.1.2 and 4.2.2. Of specific relevance are the thresholds that were used and the limitations that they may place upon the interpretation of the results.

1. The two distances, 6 km and 10 km, are only two of many thresholds that could be used. The sensitivity of the results to the distance of the observer to the coastline may require to be tested, and alternative distance bands selected.
2. The area of sea that may be visible is, in part, based upon the vertical angle between the observer and the coastline, at sea level. The sensitivity of the calculation of the vertical angle due to the resolution and scale of the DTM will reduce the area of sea computed to be visible. This will have a greater impact in the results for the closer distance band of 6 km than the further distance band of 10 km.
3. The calculation of the length of visible coastline provides a simple measure of the importance of the coastline from each observer location. However, the coastline itself will not be visible from many locations, because the local terrain may obscure its view and therefore, a more useful measure to derive is that of the 'length' of the land/sea interface in the views from a location. This could be derived from overlaying the viewshed with the land area and recording the length of the viewshed boundary which has land on one side, and sea on the other.
4. Account could be taken of the content of the land cover and variation in elevation with the distance bands used, as inputs to measure of context that may be used to describe the observers environment. This could enable additional measures to be considered, that may be valuable when considering human perception of seascapes, for example, the level of enclosure of the observer by the terrain and land cover in comparison with the distance of uninterrupted views to sea.

5. General Assumptions and Future Improvements

1. No account was taken of the effect of land cover on the visibility calculations. Therefore, the shielding effects provided by, for example, forestry were not included. This could be most significant when considering the contribution that features such as trees make to the types of views that people may value highly, for example, the effect of 'framing' a view of the coast.

   The effect of omitting the height of forest canopies on the visibility calculations will be greatest where the forestry is on a horizon close to the observer, where the angle of view of the observer to the sea will be changed the most, thus reducing the view to the sea. Similarly, the views from the sea towards the land will be most affected where the forestry is on a horizon closest to a, hypothetical, view point at sea.

   Accommodating the heights of forests within the visibility calculations can be done by using the Institute of Terrestrial Ecology (ITE) Land Cover of Great Britain (LCGB) classification, and allocating heights to the woodland areas, based upon estimates derived from Forestry Commission yield tables. However, account may also need to be taken of the growth of the forestry over time, and the effects of forest felling, opening up new views of the coast.

   It is likely that greater importance may be placed on the effect of woodlands on the *types* of views of coastal areas, for similar reasons as outlined for buildings in point 2, below.

2. No account was taken of the obscuring effects of buildings on the visibility of the land, nor on the contribution that certain types of buildings may make to the landscape. For example, views of a castle in a coastal location (*e.g.* Caernarvon) may enhance the nature of the view and the preferences that people have for such views, whereas the view of an industrial development in a coastal setting (*e.g.* an oil refinery or steel works) may reduce the expectations that people have for the quality of the view.

   The geographical models of the distribution of visibility of coastal areas, and the extent of coastal views, provide a basis for adding assessments of view content, quality and preference.

3. The height of sea level is assumed to be zero with respect to the land surface. This is not realistic because the reference for the Ordnance Survey Datum is a mean of sea level

readings from gauging stations around Great Britain, with the reference taken as Newlyn in Cornwall. Actual sea levels rise and fall by several metres.

Although this will have some effect on the results of the analyses of visibility, the magnitude will be small.

4. No account has been taken of the effects of movement on the potential visibility of coastal areas. There are two aspects of this that could be of significance. Firstly, wave movement, and breaking waves in particular, may draw attention to certain features. Such a feature may be the coastline itself, or the observer's attention may be drawn to the different types of coastlines, where cues are provided by the nature of the waves breaking (*e.g.* differences between the interface of the sea and cliffs compared to the sea and a gently sloping sand beach).

   The nature of the differences in coastal types could be accommodated by reference to the Land Cover data for the coastal areas, or by considering the changes in elevation along the coastline within a narrow range (*e.g.* 100 m).

   Secondly, movement in the scene is likely to be significant with respect to the response that people have to coastal views (see also point 7 below). A segmentation of the coastline using a number of different categories could allow the visibility of sea views to be described in terms of the dynamics of the coast. For example, a description of the visibility of a tidal estuary, compared to the same level of visibility of sea but on a more exposed area of coastline. The land cover classification (LCGB) may already accommodate such a segmentation, if correlations exist between land cover types and exposure, or water movement.

5. The digital elevation data were assumed to be accurate. However, studies by Fisher (1996) suggest that the accuracy of the 1:50 000 DTM is not as high as the figure quoted by Ordnance Survey as a mean error (RMSE 3 m). The methods commonly used to accommodate the uncertainty in DTMs require numerous realizations of the elevation surface to be calculated, and a mean to be taken of those different realizations (Fisher, 1996). This was not a practical proposition for the extent of the analysis described in this report, and the potential for errors in the visibility calculations due to inaccuracies in the source DTM should be recognized.

   The patterns of error in a DTM are usually spatially autocorrelated, *i.e.* the error at one location is closely related to the error at another location. Therefore, although there is the possibility of the absolute error in the DTM being poorer than the quoted accuracy, the relative error in height between adjacent points would be expected to be smaller. The relevance of this *expected pattern* is that the patterns of either high or low visibility would not be expected to be substantially different, although specific estimates of visibility would vary with different realization of the DTM. The impact of error in the DTM on calculations of line of sight between different hills may be less predictable, because the calculation is not between adjacent cells, rather between (or across) adjacent hills. It is expected that the magnitude of the error would be small, but no test has been carried out to assess its extent.

A test of the significance of DTM error on the derivation of coastal areas of high visibility, using 1:10 000 and 1:50 000 would be desirable if specific areas of interest were being assessed.

6. A DTM of 1:10 000 was not available for the entire coastal area (although it can now be derived from 1:10 000 OS contour data). The limitations of the 50 m x 50 m resolution data include a restricted ability to represent high frequency variation in the landscape, such as that caused by gullies, and cliffs.

   For certain areas, a further analysis using 1:10 000 data may be appropriate. This may be in areas where variability in plan and height is high, such as 'sinuous' clifflines in the south west of Wales. In such areas the use of a higher 'grain' of detail may be justified to better reflect the spatial patterns of visibility.

   At a strategic level, it is unlikely that the increase in detail can be justified because of the consequent increase in computational time that would also be required.

7. Weather, time of day and year will all contribute to the lighting conditions under which the seascape will be viewed. This is particularly true in some coastal areas where sea mist, or fog, may obscure views. Weather conditions will also impact upon the visibility of features, and the contrast between them and the background against which they are viewed. The weather conditions will also impact on the state of the sea (*i.e.* the magnitudes of the waves, the size of the breaking waves and the degree of movement of the surface of the sea). The range of conditions under which sea movement may be distinctive to an observer may be much larger than movement associated with most features that extend across large areas on land (*e.g.* swaying trees or crops).

8. The analysis of visibility of sea from land used three assumptions:

i) That the observer is 1.8 m tall, and that variations away from this value will not materially affect the general pattern of sea, or land, visibility.

ii) The radius of view was tested at 5 km and 10 km in north west Wales, but used 10 km for the entire coast.

iii) The intervals between sample points for the derivation of the patterns of visibility: 1 km. This choice was based upon previous work carried out for Scottish Natural Heritage (SNH) and research at MLURI. The assumption is that this interval of sample points is sufficient to adequately represent the variability in the visibility of the land, with different intervals selected for use at different resolutions of DTM data. A comprehensive test of the sensitivity of visibility levels at different sampling intervals has not been completed. However, preliminary results suggest that when using 50 m x 50 m resolution DTM data, the gain in detail of landscape visibility at intervals smaller than 1 km diminishes rapidly in comparison with results for 10 km, 5 km and 2 km.

9. The analysis of visibility of land from sea was extended from a radius of view of 10 km to 100 km. This was to reflect the fact that some larger mountains, greater than 10 km from the coast are visible from locations at sea, and plot of land visibility from sea would be misleading without such features being represented.

The analysis of land from sea suffers from a methodological difficulty with respect to calculating visibility from sea to land with cliffs, or terrain that slopes parallel to the vertical angle of view from a view point. An alternative approach is described under point 10 below.

10. The analysis of coastal views uses visibility values assessed for a band of points inland of the coast. No assessment has been made on the effect of choosing distances greater than 5 km from the coast for inclusion in this type of analysis, nor the significance of using points closer to the coast, at say 500 m or 250 m from the coastline.

An assessment of the effect of using points from the coastline to 10 km inland is being carried out for north-west Wales.

11. The selection of thresholds for illustrating areas of the greatest level of intervisibility between land and sea, or the extent of the seaward horizon from view points has not been calibrated against field observations or independent datasets. To provide information that is most easily used, and translatable between applications, the derivation of these thresholds should be based upon some external measure. However, the relative levels of

visibility are internally consistent to the dataset and these data will be of greatest value when used in an information system, in association with other datasets that describe characteristics of the coastal environment. Further work could be done to illustrate how such data may be used to develop strategic plans for the coastal area.

6. General Discussion and Conclusions

The methods used, or developed, within this project have provided a basis for identifying areas that have the greatest levels of intervisibility between land and sea. These methods are either new, or extensions of existing techniques of assessing landscape visibility for use in impact studies. However, they have not been directly used for coastal applications and thus a comparison with their use in other coastal applications could not be undertaken. Comparisons with other data that describe the coastal environment of Wales, specifically the visual environment, coastal views and the land use, would be desirable to validate (where that is relevant), and add value to the analyses presented in this report. Such comparisons should ensure that a more comprehensive understanding of the nature of seascapes is gained than by the use of any one method or analysis.

The datasets produced do provide different measures of the visual environment of coastal Wales. In this study, these datasets have been reported separately, however, there is considerable scope for further analyses in which the datasets are compared with each other, and patterns sought between the characteristics measured by the individual outputs. For example, the analysis of vertical angles to the horizon and that of the visibility of the land from the sea both include calculations that are based upon the intervisibility of points on land from the sea. It might be expected that the scores obtained from each of these two analyses are correlated in such a manner that would enable the identification of areas of sea for which high elevation terrain impacts upon the view and to which views from land are extensive. Equally, the areas of land from which the visibility of the sea is high may be correlated with the classification of horizon views from coastal locations.

Finally, there has not been a comparison with other studies of the Welsh coastline, where data to calibrate and aid in the interpretation of the outputs may have been useful. In particular, the incorporation of research into the composition of coastal views and their contribution to the perception of seascapes by people would help target the methods developed towards a more comprehensive description of the visual characteristics of the Welsh coastline, enabling a classification which could be used as a basis for strategic planning and impact assessments.

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Appendix 1. ***Acronyms and Abbreviations***

CCW	Countryside Council for Wales
DTM	Digital Terrain Model
GIS	Geographical Information System
ITE	Institute of Terrestrial Ecology
LCGB	Land Cover of Great Britain
MLURI	Macaulay Land Use Research Institute
OS	Ordnance Survey
RMSE	Root Mean Square Error
SNH	Scottish Natural Heritage
TIN	Triangular Irregular Network
ZVI	Zones of Visual Influence