Introduction

This paper describes the results of national analysis of coastal land use changes over a 50-year period. In 1965, the University of Reading was asked by the National Trust to conduct what was called 'the Enterprise Neptune Survey'. This was to record the costal land use in England, Wales and Northern Ireland. At the time, the Trust was concerned about increasing amounts of coastal development and the main purposes of the survey were to identify coastal features of high conservation value, to document what was present at the coast and to inform a potential land acquisition strategy by identifying areas under threat from development. These are reflected in the 1965 survey class names and annotations and highlight wider cultural values and the concerns of the Trust at the time, namely that unfettered development could irrevocably reduce the conservation value of the coast. Figure 1 shows an example of the maps and annotations for the South Devon coast at Branscombe and the Pembrokeshire coast.

(insert Figure 1 about here)

The 1965 survey was updated by the University of Leicester as part of *Neptune 2015,* the National Trust's Coast 2015 celebration. The 1965 data were digitized to create two digital products: scanned, geo-rectified basemaps of the original map sheets and a digitized vector layer. The main aim of the update project was quantify coastal land use changes over the 50 year interval which required a bespoke methodology to ve developed and applied. The National Trust were also interested identifying any emergent trends or coastline threats, comparing changes in different regions and to get some measure of the impacts of Trust's management and ownership on coastal changes. In this paper we describe the Neptune update and present a national coastal land use change analysis. The results describe overall rates of change, the relative probabilities of different types of land use change and quantify the relative impacts of the Trust's management.

However, in developing this research also identified a number of critical considerations when analysing historical thematic, especially in the context of quantifying thematic changes. These relate to a generic problem within geography of different methods being used in different mappings and surveys, for example as result of new technologies or scientific understandings of the phenomenon under consideration. These can be particularly acute in thematic data where similar class labels may hide very different methods of recording and measurement. We argue that these differences are to be expected and we emphasise the need to accommodate the impacts of any methodological differences when analysing historical data in change analyses. The issue is that methodological differences can result in areas of change being identified which only arise only because of differences in recording and reporting. Therefore it is important to consider such methodological inconsistencies when undertaking in updates in order to support robust measures analyses of change for example. Understanding the potential sources of variation in thematic data and methods for handling inconsistencies is increasingly important as more historical thematic data are digitised and made available for analysis.

UK land use mapping

There is a long tradition of mapping land use in the UK. Much early activity was concerned with the extent of individual agricultural holdings, cropping patterns or conveyance as land was sold to support urban expansion. In the 1930s, L. Dudley Stamp supervised the first Land Utilisation Survey of Britain with data collected by volunteers. The result was ~20,000 6-inch field maps that described the land use with 9 main categories plus sub-divisions (Stamp, 1937). This data has been digitised and provides a valuable resource for researchers interested in long term land use trends and their relationship with other factors (eg Comber and Brunsdon, 2015). In the 1960s Alice Coleman undertook the second Land Use Survey of Britain and volunteers mapped land use into 13 main classes (Coleman and Maggs, 1965) with 64 sub-divisions. In the 1990s, Rex Walford conducted a third land use survey for the Geographical Association (Walford, 1997). It adopted a stratified sample, recording the land use at 1000 1km squares and was undertaken by school children using a detailed survey handbook. The stratified sample survey supports statistical inferences of the stock and extent of different land use types, in the same way as the field survey component of the various Countryside Surveys in the UK (Bunce and Heal, 1984; Barr et al., 1990; Firbank et al., 2003; Carey et al 2007).

Land Use or Land Cover?

Thematic data like land use are subject to ever-changing methods and classifications (Comber et al., 2005). The UK examples cited above demonstrate this. A further issue is the recent trend for combining the concepts of land use with land cover within the same survey nomenclature, which can make it difficult to compare different datasets. Together these suggest a number of critical considerations for the update of the

National Trust's coastal land use survey and for the treatment of historical thematic data more generally by the Historical GIS (HGIS) community.

The inherent variability of thematic data is encapsulated by the land use / land cover dichotomy. Recent national land surveys have tended to record the physical properties of the land, namely land *cover*, rather than the socio-economic activities that occur on it, namely land *use*. Fisher et al (2005) document this shift from recording land use to land cover and note that it has been driven by two factors: the availability of digital satellite data and the ability to process the data using computers. They describe the data-driven nature of the classifications that have arisen as a result. Digital imagery is easily classified by applying any one of a number of statistical classification algorithms to the digital numbers in the image data. However the digital numbers record the reflectance of the physical properties of the earth's surface (land cover). They do not reliably record socio-economic activity (land use). Consider a field of grass. The cover of grass can be reliably identified from a statistical classification of remotely sensed imagery. But how this field is used cannot: the field may have animals on it, it could be an arable field in ley, it could be a large garden, it could be a park, it could be a football pitch, or it could be combinations of these. Thus identifying land *use* from digital imagery is difficult. Second, Fisher et al (2005) note that because of this situation, many land classifications are *data driven*: the classifications divides the land into what can be discerned statistically from the imagery. Consequently many large surveys have nomenclatures that include mostly land cover with one or two easily discernable land use classes (eg urban). A related consideration is the difficulty in inferring land use from land cover (Comber, 2008) because land use and land cover classes lack one-to-one relationships. As well as the grass example above (land cover to land use), a land use such as *leisure* may occur on many land covers. For these reasons, land use mapping still frequently requires a high degree of human interpretation and automated approaches have had limited success (Harrison, 2006; Rutledge et al, 2008). The only successful statistical (i.e automated) approaches to mapping land use from land cover have applied graph partitioning methods to networks of land cover (Comber et al., 2012, Walde et al., 2014) where the land cover objects and their spatial context have been very precisely defined.

For these reasons most land inventories at national and international scales mix land use and land cover (Comber 2008), even when their objective is to record one or the other (Di Gregorio and Jansen, 2000). Examples include the U.S. National Land Cover Dataset (Anderson et al, 1976), the Countryside Survey series in the UK (Fuller et al, 2002), the European CORINE dataset (EEA, 2015) and global datasets such as GLC2000 (Bartholomé and Belward, 2005).

Thematic change

There are a number of critical considerations when comparing current and historical thematic data, for example when mapping land use change. Specifically these relate to the need to separate actual changes of the phenomenon being considered from artefactual changes arising from methodological or interpretational differences. The basic problem can be summarised as follows: *every time we measure the world we do so in different ways*. Any comparative analysis of thematic data has to consider the impacts of different technologies, methodologies, classifications, algorithms, baseline data on the mapped outputs as, when taken together, these characteristics contribute to the *meaning* of the data and the classes in their widest sense: what they represent and the conceptualisations of the landscape that they embody.

The meaning and the associated semantics of any thematic data will be driven by the interaction of a many factors including the raw data from which the classification is generated and the nomenclature or classification definition. For example, there are large differences in what can be identified and measured from different raw data such as satellite imagery and field survey. The granularity of the raw data will determine what can be classified from it (5m vs. 30m resolution satellite imagery; vegetation or plant community vs. botanic field survey). Thus the meaning of any classification is implicitly dependent on raw data choices (*forest* from satellite data with 5m pixels is semantically different from *forest* classified from data with 30m pixels) as well by changes in the understanding of the phenomenon over time (Comber et al., 2003a). The result is that similarly named classes can have vastly different conceptualisations in different thematic datasets.

Variations in thematic data are driven by a number of consistent factors which ultimately combine to define the semantics, conceptualisation and meaning of any dataset. These factors generally relate to technology and measurement variations (how was it recorded?), commissioning and policy contexts (who paid for it?), institutional variations (why you see it that way?) and observer variation (what did you see?). Ahlqvist et al (2015) provides a thorough treatment of these issues.

It is instructive to consider some specific examples.

Inconsistencies are the norm in field survey. Cherrill and McLean (1995) found 26% agreement between professional surveyors from the same institution, with the same training and disciplinary background when they mapped the same 1km^2. They noted that the differences were mainly due to '*differing interpretations*'. Different surveyors will, quite reasonably, allocate the same features to a different class depending on the areal unit they have delineated, their disciplinary perspective and their interpretation of often quite vague class descriptors. Field survey is commonly presented as an objective, replicable activity in thematic mapping, but in this context it is not.

Inconsistencies are also the norm in maps from remotely sensed data. Satellite imagery is frequently used to construct land use / land cover maps and the UK has 3 national land cover maps undertaken in 1990, 2000 and 2007. These were produced by the same contractor (the Centre for Ecology and Hydrology, previously the Institute for Terrestrial Ecology), for broadly the same sponsors (Department of the Environment / Defra and latterly the various devolved UK countryside agencies) and using the same data (medium resolution, winter and summer composite satellite images). The surveys are very different in structure and content, with changes in classification (1990 vs. 2000 / 2007), representation (pixel in 1990 vs. segment in 2000 vs. field boundary in 2007) and reporting (Target classes in 1990 and Broad Habitats in 2000 and 2007). Take for example 3 maps of woodland (coniferous and broadleaved combined) in Figure 2. Whilst they are broadly similar, with the same general pattern, they describe the landscape using very different spatial structures which subtly impose different meanings to similar class labels.

(insert figure 2 about here)

As well as data structures, similarly named classes may hide very different definitions as exemplified by the class of *Bog* in the same 3 datasets. Consider the mapped extent of the class of Bog in the OS square SK, covering much of East Midlands region and the Peak District national park in the UK. In 1990 less than 1ha of bog was mapped, in 2000 it was around $75km^2$ and 164 km^2 in 2007. These apparent increases in the amount of 'Bog' arise because of the change in class definition (as well as spatial structures) as a result of a focus on habitats. This change was from a phyto-sociological definition of Bog based on water loving plant species to one that focussed on habitats, specifically to areas with greater than 0.5m of peat in 200. In 2007 the same definition applied but a different peat dataset was used.

There are many examples of variation that make the treatment of historical thematic data difficult. Such variations are endemic in geography. This is because the real world is infinitely complex and the recording of thematic features such as land use, requires the real world to abstracted, aggregated and simplified into the dataset and the classification. And abstractions will vary depending on the specific scientific choices made about data, technologies and study objectives that will themselves be driven by the funders, policy objectives, technological developments, new sensors and measurement devices.

The implications for change analyses are that thematic data collected at different times will vary for reasons that have nothing to do with changes of the feature being mapped. Rather, they will reflect an intersection of particular technological and institutional perspectives and commissioning contexts (Comber et al., 2007a). This situation is the norm in geographical information, spatial data and inventories of natural resources which rarely employ the same methods (Comber et al. 2003b). The result is that every time we measure the world we do so in different ways (Comber et al., 2005; Comber, 2008).

These are important generic issues that need to be considered in analyses of historical thematic data. Ideally, any new map would be directly comparable with the old map and a simple overlay would identify changes between the two surveys. However, because of conceptual and methodological shifts between the surveys, this would more correctly be *differences* between the two surveys composed of *actual changes* + *methodological inconsistencies* (Comber et al., 2004). In the case of the 1965 Neptune survey, a number of inconsistencies were noted in the application of the minimum mapping unit by surveyors, with clear groups of *lumpers* and *splitters*, and in the way that the inland and seaward boundaries were treated. It is difficult to say that any one approach is objectively better than another. Thus a key consideration in analysing historical thematic is to minimise inconsistencies and thereby preserve any signal of *change* within the signal of *difference*. For the Neptune update a number of rubrics were adopted to do this and to support robust measures of land use change, as described in below.

Data and Methods

In overview, the aims were to create a new dataset of coastal land use dataset, to compare this with the 1965 dataset and to quantify and land use changes, whilst ensuring that robust measures of change were produced. This section describes the 1965 dataset and the methodology that was adopted for the update.

The Neptune land use survey was commissioned in 1965 due to concerns over urban expansion and coastal development as well as the National Trust's desire to identify coastal areas of high conservation value. Although known for its historic houses, the Trust protects large areas of historic landscapes in England, Wales and Northern Ireland. It is UK's second biggest land owner (>250,000 ha) and owns or manages ~1,300 km coastline (out of 11,000 km). The Trust is primarily a conservation organisation and has an open access policy on much of its land.

The original survey was conducted by 34 Geography students and 3 members of staff from the University of Reading over the summer holidays. Each surveyor was responsible for a particular section of coastline which they walked, usually camping overnight. They were instructed to climb to a vantage point, record the land use types they could see, then to walk transects across the landscape to validate their observations. The surveyors recorded their findings on 2½ inches to 1 mile (1:25,000) Ordnance Survey (OS) basemaps shading in the land use classes as they went. In addition annotations describing the quality of the coastline were included in many areas, as seen in Figure 1.

The surveyors received one day of training on how to apply the classification, the level of spatial detail required (what might now be called a minimum mapping unit), how to treat the inland boundary, etc. However, they very much learnt, developed and refined their surveying skills on the job, with little if any supervision between the start and finish of the survey. Consequently the surveyors had to make pragmatic decisions about how to map features in the field. This resulted in variation between surveyors. For example, although nominally the aim was to survey a 1km strip inland from the coastline, due to the varied nature of the terrain and the limitations of the map sheets, the width of the coastal strip ranges in size from 150m to 7km. The National Trust recently digitised the 1965 data.

For the 2014 Neptune land use update and change mapping, the approach taken was to edit the 1965 vector layer to reflect current coastal features. The update layer maintained the extent and original interpretations of the 1965 land use and areas where actual change was observed were updated spatially and thematically. The mapping was undertaken in QGIS, an open source GIS and those undertaking the update were supported by having the following digital resources within their GIS sessions: the 1965 vector layer, the original scanned OS basemaps, current 1:25,000 Ordnance Survey topographic maps and current aerial photography (Bing) provided by the OpenLayers plugin for QGIS. Examples of the data are shown in Figure 3.

(insert Figure 3 about here)

The 1965 land use classes and 2014 updates are described in Table 1. Some of the original classes were dropped or refined. In particular, the following changes to the classification were made:

1. A new class of *Inland Water* was created. In 1965, inland water areas were left as holes in the map. In many cases the historical OS basemaps showed an inland water

body as being present in these holes. These were retrospectively mapped in the update where possible.

2. *Farming land* was renamed *Open countryside* to reflect both the increased diversity of rural land use, such as land permanently or temporarily set aside from agriculture. This was the default land use class.

3. *Industrial buildings* was renamed *Industry* to reflect the fact that this class included more than just buildings, for example features such as quarries.

4. *Industrial wasteland* was renamed *Wasteland*, because it was not always clear if the observed wasteland areas (previous and current) were associated with industrial activity or not.

5. *Caravans in woodland*, *Caravans in quarries* and *Blockhouses* were dropped as there were few instances of these caravan classes in the 1965 data and Blockhouses are difficult to identify from aerial photography.

6. New descriptors were added for *Shack development*, *Open countryside, Woodland* and *Cared-for Non-Productive* to reflect current interest in solar farms, green houses and plantation forestry.

Code	**1965 Class**	**Retained in 2015**	**Notes**
1	Built-up urban land	Yes	
2	Shacks	Yes	Retain where evidence of work related (fishing etc) or day accommodation (beach hut).
3	Industrial buildings	Yes	Renamed *Industry*.
4	Industrial waste land	Yes	Renamed *Wasteland* includes Brownfield sites.
5	Caravan sites	Yes	Caravan site, holiday camp, camping sites, static caravans, mobiles homes.
6	Defence	Yes	
7	Blockhouses	No	
8	Transport	Yes	
9	Farming land	Yes	Renamed *Open countryside*. The default

			land use class. Includes open land as varied as dunes and farmland. Greenhouse and solar farms were flagged.
10	Woodland	Yes	All forms of tree cover. Plantation forestry was flagged.
11	Cared for but Non-Productive	Yes	This class represents an 'outdoor sport and leisure' class; all mown grass and similar areas such as parks, golf courses and sports grounds.
12	Caravans in woodland	No	
13	Caravans in quarries	No	
14	Amenity water	Yes	Areas with marinas, leisure boats & harbours and workshops.
15	Inland water	New	New class for sizable inland water areas that were frequently included as holes in 1965 data, which were flagged as such in 2014.

Table 1. The classes used in 1965 and their modification for the survey update.

In 1965, the choice of where to place the boundaries was determined by the individual surveyor. A large amount of spurious changes would be generated if interpreter variations in boundary placement were not considered in the update.

The inland boundary was inconsistently treated in the 1965 survey. Typically it would follow features such as roads or railways, or the edge of the individual map sheets and in estuaries it continued upstream as far as the first crossing point of the river (bridge or ferry). For the update, these inland boundaries were maintained, regardless of whether they related to the modern day landscape.

The seaward boundary was rather more complex. In 1965, the surveyors mapped to one of the following: the mean high water line; the hard coastline (e.g. edge of promenades, docks, cliff tops); an inland feature e.g. the landward side of a road or railway close to the shoreline; an arbitrary line that probably had relevance 1965 but is difficult to decipher now. Examples are shown in Figure 4. In order to accommodate this variation and to allow for the possibility of actual coastal changes such as erosion, accretion, reclamation and port expansions, a set of dedicated rules were developed as shown in Table 2. The key principle was that, regardless of the 1965 seaward boundary line, if there was no change, then the coastline was left unaltered.

(insert figure 4 about here)

1965 Coastline	**State**	**Action**
Mapped to 1965 Mean High Water	Unchanged	None – leave as is
	Changed e.g. erosion, or new land	Map to 2014 Mean High Water
Mapped to Coastline (e.g. cliffs, land edge etc)	Unchanged	None – leave as is
	Changed e.g. erosion or new areas	Map to new coastline
Mapped to Inland Feature (e.g. road, railway etc)	Unchanged	None – leave as is
	Changed – coastline moved inside current lines e.g. erosion	Map to new coastline
	Changed e.g. new land added beyond omitted area	Map to new coastline and flag as a Positional Error
Mapped to indeterminate line (between high water and land edge)	Unchanged	None – leave as is
	Changed e.g. erosion, new land	Map to new coastline and flag as a Positional Error

Table 2. The ruleset for the treatment of seaward boundary inconsistencies.

Two general kinds of error were observed in the data: class label errors and positional errors. Where found, these errors were flagged in the update, enabling their removal from any statistical analysis of change. Positional errors in the 1965 data were identified by inspecting current and historical topographic basemaps. Classification errors were evident where features existed on the 1965 Ordnance Survey maps and were still present in 2014, but were mislabelled or not mapped in the original survey. This may because the features were not clearly visible to the 1965 surveyor on the ground. An example is shown in Figure 5 where many features are clearly marked on the 1965 map and are still present today but not recorded by the original surveyor. In the 2014 update these were flagged as errors, shown in red in Figure 5c, and an alternative 1965 class suggested. Positional errors occurred where the 1965 vector layer did not correctly overlay the modern aerial photography and OS basemaps. Such can arise when the old OS maps were digitised and stretched to fit onto more accurate modern data or because of low accuracy reference layers. Where observed, positional errors were flagged in the update to allow them to be removed from the change analysis.

(insert Figure 5 about here)

The final dataset therefore contained the following attributes: the original 1965 land use class, the current land use class, an error flag and where appropriate an alternative 1965 land use class.

A critical part of any mapping project is quality assurance. Each completed map tile was reviewed by a second person working on the project to identify any errors. Review comments were stored in a separate spatial data file and returned to the original mapper for correction. This eliminated the vast majority of errors and inconsistencies and promoted an over-arching continuity of interpretation in the update with no single person working on the update project able to persistently misclassify a particular land use type, for example.

Results

change was calculated by comparing the 1965 class with the 2014 class. The alternative 1965 class was used where it was indicated and any features with positional errors were omitted. The spatial distribution and magnitude of the land use changes are shown in Figure 6. This uses 10km hexagonal areas (hexbins) recast as cartograms with the size of the hexagons reflecting the proportion of surveyed land that had changed within the hexagon area. It is evident from Figure 6 that there are areas of high change in the North East, around the Hampshire coast, North and South Wales, for example.

(insert figure 6 about here)

The total areas for each land use class in 1965 and 2014 are shown in Table 3. The data for Northern Ireland are excluded due to data quality issues described in the project report. Some of the major changes in stocks include increases in *Urban* of 17,557 ha, from 8.5% to 12.1% of the coastal area, in *Industrial* by 3,651 ha from 1.9% to 2.6% and in *Woodland* by 8,384 ha from 4.2% to 5.9%. Important losses were found to *Defence*, which decreased by 4,209 ha from 3.5% to 2.7% of the total area, and to *Open Countryside*, which decreased by 14,800 ha from 71.6% to 68.6%. Other land uses, although with smaller areas, also exhibited significant changes, for example *Caravans* increased by 44% of its 1965 area from 4871 ha to 7024 ha, *Transport* by 56% from 3816 ha to 5970 ha and *Amenity Water* increased nearly 10-fold from 57 to 550 ha.

Class	Area 1965	% 1965	Area 2014	% 2014
Null	23412	4.73	1808	0.37
Urban / Built-up	42074	8.5	59631	12.05
Shacks	859	0.17	161	0.03
Industry	9430	1.91	13081	2.64
Wasteland	2926	0.59	3539	0.72
Caravans, etc	4871	0.98	7024	1.42
Defence	17356	3.51	13147	2.66
Blockhouses	208	0.04	0	0
Transport	3816	0.77	5970	1.21
Open Countryside	353984	71.55	339184	68.56
Woodland	20899	4.22	29283	5.92
Cared for but Non-Productive	14626	2.96	17989	3.64
Caravans in Woods	31	0.01	0	0
Caravans in Quarries	11	0	0	0
Amenity water	57	0.01	550	0.11
Inland water	182	0.04	3376	0.68

Table 3. The coastal land use stocks in 1965 and in 2014.

The standard approach for quantifying not just the magnitudes of land use change but also their direction is the change matrix. This is sometimes referred to as the *correspondence matrix* or the *transition matrix*. It tabulates spatially coincident land use areas and represents the two time periods by rows and columns. The diagonal elements show the areas that have stayed the same and the off-diagonal elements describe the areas of the class-to-class changes. A full description of the correspondence matrix is given in Congalton (1991). Table 4 is the full change matrix and Table 5 shows the change matrix for just National Trust land. In both cases rows indicate the 1965 classes and columns the 2014 classes.

The key losses from the 1965 classes can be identified by reading across the rows in the full change matrix (Table 4). The idea is to compare the diagonal values, representing the area of no change, with the off-diagonal values in each row representing the losses. These suggest extensive conversions from *Urban* to *Open*

Countryside, *Woodland* and *Cared for but Non-Productive*, from *Industry* to *Wasteland* and *Open Countryside*, from *Wasteland* to *Industry* and to *Open Countryside* and from *Open Countryside* to *Urban*, *Industry*, *Caravans*, *Woodland* and *Cared for but Non-Productive*. For other land uses, much of the 1965 area remained unchanged (i.e. large diagonal values relative to sum of the row values) but with other important losses. Examples of these changes include changes from *Caravans* to *Urban* and *Open Countryside*, large changes from *Defence* to *Urban*, *Transport* and *Open Countryside* and large changes from *Cared for but Non-Productive* to *Urban* and *Open Countryside*.

The key gains to the 2014 classes can be identified by reading down the columns in the full change matrix (Table 4) and again to compare the diagonal values, representing the area of no change, with the off-diagonal values in each column, which in this case represent the gains. These suggest large land use changes to *Urban* from *Open Countryside* and *Cared for but Non-Productive* and small gains from nearly every other class, to *Industry* from *Open Countryside*, to *Wasteland* from *Industry*, to *Caravans* from *Open Countryside* (greater than the losses) to *Woodland* from *Open Countryside* and large gains to *Cared for but Non-Productive* from *Open Countryside*. Small gains to *Open Countryside* were observed from nearly all classes.

2014 class / **1965 class**	**Null**	**Urban / Built-up**	**Shacks**	**Industry**	**Wasteland**	**Caravans, etc**	**Defence**	**Blockhouses**	**Transport**	**Open Countryside**	**Woodland**	**Cared for**	**C in Woods**	**C in Quarries**	**Amenity water**	**Inland water**
Null	0	2908	24	2431	295	101	295	0	1869	11864	547	865	0	0	447	1765
Urban / Built-up	160	40268	10	251	76	190	42	0	42	518	261	228	0	0	22	6
Shacks	28	216	63	3	14	134	0	0	1	330	24	45	0	0	0	1
Industry	36	426	1	5406	1297	33	1	0	366	1312	316	125	0	0	1	110
Wasteland	16	134	0	431	529	34	4	0	27	1341	266	51	0	0	3	89
Caravans, etc	52	453	1	14	58	3068	2	0	1	979	109	126	0	0	2	6
Defence	58	531	0	268	210	81	11832	0	562	3255	200	319	0	0	17	24
Blockhouses	15	1	0	69	0	1	0	0	1	84	17	18	0	0	0	1
Transport	31	411	0	379	207	10	0	0	2327	323	58	54	0	0	9	7
Open Countryside	1359	12548	39	3673	782	3112	938	0	707	315765	9474	4422	0	0	46	1120
Woodland	18	452	1	101	30	153	29	0	2	2398	17506	172	0	0	0	36
Cared for	33	1281	23	51	26	92	3	0	65	992	492	11549	0	0	3	17
Caravans in Woods	0	0	0	0	0	10	0	0	0	7	1	13	0	0	0	0
Caravans in Quarries	0	1	0	0	0	4	0	0	0	0	6	0	0	0	0	0
Amenity water	1	0	0	3	15	0	0	0	0	9	3	1	0	0	0	25
Inland water	0	0	0	0	0	1	0	0	1	7	3	0	0	0	0	170

Table 4. The full change matrix showing the areas (ha) of different land uses nationally. Rows indicate the 1965 classes and the columns the 2014 land use classes.

2014 class **1965 class**	**Null**	**Urban / Built-up**	**Shacks**	**Industry**	**Wasteland**	**Caravans, etc**	**Defence**	**Blockhouses**	**Transport**	**Open Countryside**	**Woodland**	**Cared for**	**C in Woods**	**C in Quarries**	**Amenity water**	**Inland water**
Null	0	6	0	0	0	0	0	0	0	381	19	2	0	0	0	100
Urban / Built-up	0	193	0	0	1	0	1	0	0	20	9	4	0	0	0	0
Shacks	1	3	2	0	0	1	0	0	0	26	2	1	0	0	0	0
Industry	0	0	0	2	10	5	0	0	0	18	0	5	0	0	0	0
Wasteland	0	1	0	2	7	0	0	0	0	101	4	1	0	0	0	1
Caravans, etc	1	2	0	0	0	8	0	0	0	65	9	4	0	0	0	0
Defence	6	0	0	0	6	1	209	0	0	734	0	1	0	0	0	18
Blockhouses	0	0	0	0	0	0	0	0	0	9	1	2	0	0	0	0
Transport	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
Open Countryside	180	61	3	11	4	22	11	0	0	32207	1118	111	0	0	0	45
Woodland	4	7	0	0	0	3	0	0	0	283	2200	7	0	0	0	1
Cared for	3	6	1	0	0	2	0	0	0	127	60	515	0	0	0	0
Caravans in Woods	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Caravans in Quarries	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amenity water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inland water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9

Table 5. The change matrix for the areas of land use (ha) on National Trust land. Rows indicate the 1965 classes and the columns the 2014 land use classes.

Class	non-NT land					NT Land					Comments on differences
	Same	Loss	Gain	Loss %	Gain %	Same	Loss	Gain	Loss %	Gain %	
Null	0	22904	1613	100.0	100.0	0	509	195	100.0	100.0	Incomparable class
Urban / Built-up	40075	1772	19277	4.2	32.5	193	35	86	15.2	30.7	Greater loss on NT land but some gains due to new visitor centres
Shacks	61	762	94	92.6	60.7	2	34	4	93.7	65.7	Little difference
Industry	5404	3985	7662	42.4	58.6	2	39	13	95.1	86.9	Greater losses and gains on NT land than on non-NT land
Wasteland	523	2287	2988	81.4	85.1	7	109	22	94.1	75.8	Less gain and greater losses on NT land
Caravans, etc	3060	1722	3923	36.0	56.2	8	81	34	91.2	81.1	Greater losses on NT land (91%) than nationally (36%)
Defence	11622	4757	1302	29.0	10.1	209	767	13	78.5	5.7	Greater losses, mainly due to the NT purchase of Orford Ness
Blockhouses	0	197	0	100.0	NA	0	12	0	100.0	NA	Discontinued class
Transport	2324	1489	3644	39.0	61.1	3	1	0	15.7	0.0	Much greater gains on non-NT land compared to NT land
Open Countryside	283558	36654	21655	11.4	7.1	32207	1565	1765	4.6	5.2	Greater losses on non-NT land than on NT land
Woodland	15306	3088	10556	16.8	40.8	2200	305	1221	12.2	35.7	Greater losses on non-NT land than on NT land
Cared for	11034	2880	6302	20.7	36.4	515	198	137	27.7	21.1	Greater gains on non-NT land than on NT land.
Caravans in Woods	0	31	0	100.0	NA	0	0	0	NA	NA	Discontinued class
Caravans in Quarries	0	11	0	100.0	NA	0	0	0	NA	NA	Discontinued class
Amenity water	0	56	550	100.0	100.0	0	0	0	0	0	Incomparable class
Inland water	161	12	3041	6.7	95.0	9	0	165	0.0	94.8	Little difference

Table 6. The areas, in ha, of losses and gains and that stayed the same associated with different land use classes on National Trust land (NT land) and Non-National Trust land (non-NT land).

Table 5 shows the change matrix for National Trust (NT) land. Comparing Tables 4 and 5, there are obvious differences in the distribution of land use classes between NT land and other land (non-NT land), with less *Urban* and *Industrial* land and much greater proportions of *Open Countryside* on NT land. The comparative losses and gains of coastal land use changes on non-NT land NT land are shown in Table 6, with some comments on the observed differences. The possible effects of NT management are evident from the losses and gains. For example greater losses to the classes of *Urban*, *Wasteland* and *Caravans* were found on NT land, greater losses to *Open Countryside* and *Woodland* were found on non-NT land, and greater gains to *Cared for but Non-Productive* were found on non-NT land. Interestingly there are some apparent anomalies: much greater losses to *Defence* were found on NT which was mainly due to the Trust's purchase of Orford Ness, a 900 ha cold war military base. Greater gains to *Industry* were found on NT land, although only a 13 ha conversion form *Industry,* representing small scale, local activities on land that was brought into the Trust's management.

Odds Ratios can be used to compare the probabilities of change in different zones such as on NT land and non-NT land. The areas of change and no change for different zones are summarised in 2 by 2 contingency tables. These support a number of statistical analyses as described in Comber et al (2016) including Odds Ratios which provide comparative measures of land use change. The odds ratio, θ, of the relative likelihood of change is defined as follows:

$$\theta = \frac{Odds(change|Zone_1)}{Odds(change|Zone_2)} \text{ (Equation 1)}$$

An odds ratio of 1 indicates change is equally likely to occur in both zones. If NT land is $Zone_1$ and non-NT land is $Zone_2$ then an odds ratio of greater than 1 indicates that change is more likely to occur on NT land. If the odds ratio is less than 1 then change is more likely on non-NT. A chi-squared test provides a measure of unexpectedness of the contingency table values and the associated *p-values* indicate the significance of the differences, under the assumption of equal distributions of change and no change between the zones.

Table 7 shows the Odds Ratios of change for both losses and gains on NT land relative to change on non-NT land. The data in Table 7 are drawn from Table 6, with some rounding differences. The calculation of the relative likelihood of loss from the class *Urban* illustrates the calculation of ORs:

Odds of Urban loss on NT land: 35/193 = 0.1813472

Odds of Urban loss on non-NT land: 1772/40075 = 0.04421709

$\theta = (35/193)/(1772/40075) = 4.10$

In this case, the likelihood of urban loss on NT land is 4.10 times greater than on non-NT land. The significance can be tested applying a chi-squared test to the 2 by 2 contingency matrix.

It is possible to make some statements comparing the observed changes on NT land and non-NT land for classes with areas greater than 100ha and where the differences statistically were found to be significantly different (i.e. with a *p-value* of less than 0.05). The data in Table 7 supports the following statements comparing changes on NT and non-NT land:

1. Significantly greater likelihoods of loss on NT land were found for *Urban*, *Wasteland* and *Defence* land uses (4.04, 3.63 and 8.95 times greater respectively).

2. Significantly greater likelihoods of loss on non-NT land were found for *Open Countryside*, *Woodland* and *Cared for but Non-Productive* land uses (2.63, 1.45 and 1.47 times greater respectively).

3. Significantly greater likelihoods of gain on non-NT land were found for *Defence*, *Open Countryside*, *Woodland* and *Cared for but Non-Productive* land uses on non-NT land (1.85, 1.39, 1.25 and 2.13 times greater respectively).

Class	**1965 Area**	**OR loss**	**p-value loss**	**2014 Area**	**OR gain**	**p-value gain**
Urban / Built-up	227	4.04	0	278	0.92	0.575
Shacks	36	1.18	1	7	1.24	1
Industry	41	26.19	0	15	4.67	0.048
Wasteland	116	3.63	0.001	28	0.55	0.263
Caravans, etc	89	18.36	0	42	3.34	0.002
Defence	976	8.95	0	222	0.54	0.039
Blockhouses	12	0.06	NA	0	1	NA
Transport	3	0.29	0.779	3	0.1	0.154
Open Countryside	33773	0.38	0	33972	0.72	0
Woodland	2505	0.69	0	3421	0.8	0
Cared for but Non-Productive	713	1.47	0	652	0.47	0
Caravans in Woods	0	0.02	NA	0	1	NA
Caravans in Quarries	0	0.04	NA	0	1	NA
Amenity water	0	0.01	NA	0	0	NA
Inland water	9	0.7	0.912	174	0.96	1

Table 7. The Odds Ratios (OR) of loss and gain from and to different land classes on NT land compared to non-NT land.

Discussion and Conclusion

The results indicate large scale increases in *Urban*, *Woodland* and in the leisure classes (*Caravans*, *Cared for but Non-Productive*, *Amenity Water*) and a decline in amount of *Defence* land. These may have been expected given well documented trends in urban expansion, agricultural diversification, increases in leisure activities and the reductions in UK military establishments. Interestingly a number of land use classes were subject to high amounts of churn, where a class experiences losses in one location and gains in another. High degrees of churn were evident in the following classes: *Wasteland*, with equal losses and gains, *Caravans* and *Cared for but Non-Productive* which gained over twice the area they lost, and *Industry* and *Transport* which gained just under twice as much as they lost. More detailed analyses of churn are possible but these require careful consideration of the spatial units of analysis and consideration of the MAUP (the modifiable areal unit problem, Openshaw, 1984). Under the MUAP, different rates of churn would be expected at the same location, depending on the spatial extent scope of the analysis, for example using zones, reporting units, etc.

The change matrix quantifies class-to class changes and the results show high levels of change to *Urban* from all classes and changes from *Industry* to *Wasteland* and *Open Countryside*. Urban and industrial encroachment of open spaces was observed with large changes from *Open Countryside* to *Urban* and *Industry*, as well as to the leisure classes of *Caravans* and *Cared for but Non-Productive*. Odds ratios allowed the quantify differences between National Trust and non-National Trust land to be quantified, providing relative probabilities of change and quantifying the impacts of different land management regimes, although one of the assumptions made in the analysis was that the Trust's management was present in 1965. This means that some of the ratios may over represent urban, industrial and leisure development on NT land. However, the National Trust's management clearly has had a dampening effect on urban and leisure related land use expansion. These benefits reflect the stated aims the Trust, namely to protect historic landscapes, to provide public access to the countryside, and protect and conserve coastal areas from development and urban expansion.

The methods applied in this paper were based on the principles laid out by Gauld et al (1991; 1992) in their work examining land cover changes mapped from historical and current aerial photography as applied in Comber et al (2003b). These reflect the need to consider the different sources of variability in mapping, mainly arising from observer variations which may result in different interpretations and mappings of the same landscape. The ideas developed Gauld et al were extended to consider some of the wider issues that result in methodological changes and their implications for thematic data analysis. These considerations fill an important gap in Historical GIS (HGIS) research and support robust analyses of the increasing amounts of digital thematic data being made available. HGIS has developed a number of archives, protocols and tools to support temporal queries of spatially coincident digital data (for example, www.geolytics.com; Bol and Ge, 2005; the National Historical Geographic Information System https://www.nhgis.org) and historical spatial data has been used to underpin a wide range of place-based research in the social sciences (Knowles, 2005; Gregory and Healey, 2007; Gregory and Ell, 2007). This includes analyses of the changes in the spatial distribution of different social classes (Orford et al., 2002), mortality (Gregory, 2008; Thornton and Olson 2011), family composition (van Leeuwen and Zijdeman 2014) and to examine segregation and working patterns (Páez et al, 2014; Dunae et al., 2013).

To support this work, the HGIS community have tackled a number of methodological issues associated with historical changes in spatial frameworks, geographic reporting units or administrative boundaries, where the need to is link one set of *counts* of some phenomenon over one set of geographic units to another. But as yet little work has considered methods for analysing historical thematic data where the critical issues are wider than changes in spatial frameworks. They include new data, new technologies, new reporting objectives, new scientific understandings and highly subjective interpretation of classes, which together changes the way that similarly labelled classes are constructed conceptually as well as spatially. Methods to minimise methodological and observer inconsistencies to support retrospective analyses of historical thematic data are critical if such data are to be robustly exploited. For some subject areas, e.g. geology or soil science, differences between mappings probably reflects changes in scientific understanding rather than physical changes on the ground (Comber et al., 2008b). Domains such as land use may be similarly subject to semantic and conceptual changes in scientific understanding over time, but the process they record is more temporally dynamic and therefore more likely to be subject to actual changes on the ground. The result of these epistemological changes to activity of measurement is the construction of new and different conceptualisations of land use and land cover. Examples are provided by Comber et al (2005) who illustrate the divergent ways that the class of 'Forest' is conceptualised and Grainger (2007) who documents changes in the way that 'tropical rainforest; is conceived, and measured. For these reasons, analyses of historical thematic data need to be able separate out any signal of actual change from the noise of methodological, semantic and conceptual difference (Comber et al, 2004a; 2004b; 2005). An oft-cited approach to handling divergent semantics through the adoption of formal metadata standards. However, while metadata document many aspects associated with data production, they fail to describe the semantics, meaning and conceptualisations embedded in the dataset and its classes. Importantly, they are not designed to help users understand the data and provide no information about how the classes are constructed and what they *mean* in the widest sense (Fisher et al 2009). Comber et al (2007b), Fisher (2009) and Comber et al (2015) provide thorough treatments of this topic.

In conclusion, this paper describes recent research that quantified coastal land use changes, the probabilities of different types of land use change and the impacts of different land management regimes management. In so doing, it has highlighted and addressed a number of important methodological issues associated with the analysis of historic thematic data, such as land use, related to the impact of inevitable methodological differences and changes over time in the way that thematic features are measured. These differences have important implications for analyses of historic thematic data, for example for retrospective analyses of old data or for quantifying changes over time. Any such analyses need to consider how to overcome observer variations, changes in recording methods or technologies and their impacts on what the thematic classes mean in their widest sense. This is a new set of considerations to those already well established in HGIS. The methods used in this study, based on the recommendations of Gauld et al (1991, 1992) and applied in Comber et al (2003b) offer a robust way forward. They suggest the need to accept the original boundaries between thematic classes where possible, to consider the concepts underneath the class labels driven by measurement and changes in survey objectives, and to flag any inconsistences or errors in the original data when they are suspected. In short they suggest adopting the mind-set of the original mapper.

Acknowledgements

This research was supported by the National Trust Neptune Coastline Campaign. The authors would like to thank the 1965 surveyors and those who worked on the 2014 update: Connor Dunne, Luke Slater and Lt Col Ahmed Tukur.

References

Ahlqvist O, Varanka D, Fritz S and Janowicz K 2015 *Land Use and Land Cover Semantics - Principles, Best Practices and Prospects:* CRC Press

Anderson JR Hardy EE Roach JT and Witmer RE 1976 *A Land Use and Land Cover Classification System for Use with Remote Sensor Data* US Geological Survey Professional Paper 964 p 28 Reston VA

Bartholomé E and Belward AS 2005 GLC2000 a new approach to global land cover mapping from Earth observation data *International Journal of Remote Sensing* 269 1959-1977

Bol P and Ge J 2005 China historical GIS *Historical Geography 33* 150-152

Barr CJ Bunce RGH Clarke RT Fuller RM Furse MT Gillespie MK Groom GB Hallam CJ Hornung M Howard DC and Ness MJ 1993 *Countryside Survey 1990: main report (Countryside 1990 vol 2)* http://nora.nerc.ac.uk/4329/1/N004329RE.pdf

Carey PD Wallis S Chamberlain PM Cooper A Emmett BA Maskell LC McCann T Murphy J Norton LR Reynolds B and Scott WA 2008 *Countryside survey: UK results from 2007* NERC/Centre for Ecology & Hydrology, 105pp. (CEH Project Number: C03259)

Bunce RGH and Heal OW (1984) Landscape evaluation and the impact of changing land-use on the rural environment: the problem and an approach. In *Planning and ecology* R D Roberts and T M Roberts (eds) pp164-221 London Chapman & Hall

Cherrill A and McClean C 1995 An investigation of uncertainty in-field habitat mapping and the implications for detecting land-cover change *Landscape Ecology* 10 5-21□

Coleman A and Maggs KRA 1965 *Land use survey handbook* Isle of Thanet Geographical Association; Fourth Scottish Edition

Comber A Fisher, P and Wadsworth R 2003a Actor Network Theory: a suitable framework to understand how land cover mapping projects develop? *Land Use Policy*, 20: 299–309.

Comber AJ Birnie RV and Hodgson M 2003b A retrospective analysis of land cover change using polygon shape index *Global Ecology and Biogeography* 12 207-215

Comber A Fisher P and Wadsworth R 2004a Integrating land cover data with different ontologies identifying change from inconsistency *International Journal of Geographical Information Science* 187 691-708

Comber A Fisher P and Wadsworth R 2004b Assessment of a Semantic Statistical Approach to Detecting Land Cover Change Using Inconsistent Data Sets *Photogrammetric Engineering and Remote Sensing* 70 931-938

Comber A Fisher P and Wadsworth R 2005 What is land cover? *Environment and Planning B: Planning and Design* 32 199-209

Comber AJ Fisher PF and Wadsworth RA 2007a Dynamic metadata user-focused metadata for spatial data geographical information and data quality assessments

AGILE 2007 10th AGILE conference on Geographic Information Science eds Monica Wachowicz and Lars Bodum 8th May Aalborg

Comber A Fisher P and Wadsworth R 2007b Land cover: to standardise or not to standardise? Comment on 'Evolving standards in land cover characterization' by Herold et al. *Journal of Land Use Science*, 2 287–291

Comber AJ 2008a The separation of land cover from land use using data primitives *Journal of Land Use Science* 34 215-229

Comber AJ Fisher PF and Wadsworth RA 2008b Semantics Metadata Geographical Information and Users Editorial *Transactions in GIS* 123 287–291

Comber AJ Brunsdon CF and Farmer CJ 2012 Community detection in spatial networks Inferring land use from a planar graph of land cover objects *International Journal of Applied Earth Observation and Geoinformation* 18 274-282

Comber A and Brunsdon C 2015 A spatial analysis of plant phenophase changes and the impact of increases in urban land use *International Journal of Climatology* 35 972-980

Comber A Fisher P and Wadsworth R 2015 A text mining analysis of land cover semantic overlap. Pp 191-210 in Ola Ahlqvist, Dalia Varanka, Steffen Fritz, and Krzysztof Janowicz (eds), *Land Use and Land Cover Semantics - Principles, Best Practices and Prospects*: CRC Press

Comber A Balzter H Cole B Johnson SCM Oguto B and Fisher P 2016 Methods to quantify regional differences in land cover change *Remote Sensing* 8 176

Congalton RG 1991 A review of assessing the accuracy of classifications of remotely sensed data *Remote Sensing Environment* 37 35–46

Di Gregorio A and Jansen LJM 2000 *Land Cover Classification System Classification Concepts and User Manual* FAO Rome

Dunae PA Lafreniere DJ Gilliland JA and Lutz JS 2013 Dwelling Places and Social Spaces Revealing the Environments of Urban Workers in Victoria Using Historical GIS *Labour/Le Travail* 721 37-73

EEA 2015 CORINE land cover http//wwweeaeuropaeu/publications/COR0-landcover

Firbank LG, Barr CJ, Bunce RGH, Furse MT, Haines-Young R, Hornung M, Howard DC, Sheail J, Sier A and Smart SM 2003 Assessing stock and change in land cover and biodiversity in GB: an introduction to Countryside Survey 2000 *Journal of Environmental Management, 67 207-218*

Fisher PF Comber AJ and Wadsworth RA 2005 Land use and Land cover Contradiction or Complement Pp 85-98 in *Re-Presenting GIS* eds Peter Fisher David Unwin Wiley Chichester

Fisher PF Comber AJ and Wadsworth RA 2009 What's in a name? Semantics, Uncertainty Standards and Data Quality. In *Proceedings of the International Symposium on Spatial Data Quality*, 5-8th July 2009 St John's, Canada http://www.isprs.org/proceedings/XXXVIII/2-C6/scan-ISPRS-combined.pdf

Fuller RM Smith GM Sanderson JM Hill RA and Thomson AG 2002 The UK Land Cover Map 2000 construction of a parcel-based vector map from satellite images *The Cartographic Journal 39*1 15-25

Gauld JH Bell JS Towers W and Miller DR 1991 *The measurement and analysis of land cover change in the Cairngorms* Report to the Scottish Office Environment Department and the Scottish Office Agriculture and Fisheries Department HMSO London

Gauld JH Miller DR Dry FT Towers W Moir AD and Aspinall RJ 1992 *An analysis of methodology used to measure land cover change with special reference to an evaluation of GIS performance* Report to the Scottish Office Environment

Department and the Scottish Office Agriculture and Fisheries Department HMSO London

Grainger A 2007 The influence of end-users on the temporal consistency of an international statistical process: the case of tropical Forest Statistics *Journal of Official Statistics* 23 553-592

Gregory IN and Ell PS 2007 *Historical GIS technologies methodologies and scholarship* Vol 39 Cambridge University Press

Gregory IN and Healey RG 2007 Historical GIS structuring mapping and analysing geographies of the past *Progress in Human Geography 31*5 638-653

Gregory I 2008 *Different Places Different Stories Infant Mortality Decline in England and Wales 1851-1911 Annals of the Association of American Geographers* 98 773-794

Harrison AR 2006 National land use database land use and land cover classification *O Office of the Deputy Prime Minister Ed ed London UK Queen's Printer and Controller of Her Majesty's Stationery Office* 81

Knowles AK 2005 Emerging trends in historical GIS *Historical Geography 33* 7-13

Openshaw S 1984 *The modifiable areal unit problem* Geo Abstracts, University of East Anglia

Orford S Dorling D Mitchell R Shaw M and Smith GD 2002 Life and death of the people of London a historical GIS of Charles Booth's inquiry *Health & Place 8*1 25-35

Páez A Hernández FL Ruiz M and Logan J 2014 Micro-geography of segregation evidence from historical US census data *Social-spatial segregation Concepts processes and outcomes* 91

Rutledge DT Price R Briggs C and Cowell S 2008 *Geospatial land-use classification for New Zealand review and recommendations* Official Statistics Research Series 4 Available from wwwstatispheregovtnz/osresearch

Stamp LD 1937*The Land of Britain The Report of the Land Utilisation Survey of Britain* Geographical Publications

Thornton P and Olson S 2011 Mortality in late nineteenth-century Montreal Geographic pathways of contagion *Population studies 65*2 157-181

van Leeuwen MH and Zijdeman RL 2014 Digital humanities and the history of working women a cascade *The History of the Family 19*4 411-425

Walde I Hese S Berger C and Schmullius C 2014 From land cover-graphs to urban structure types *International Journal of Geographical Information Science 28*3 584-609

Walford R 1997 *Land Use-UK: a survey for the 21st century* Geographical Association

List of Figures

Figure 1. An example of the annotated Neptune coastal land use survey map sheets a) for Branscombe on the South Devon coast, and b) the Pembrokeshire coast.

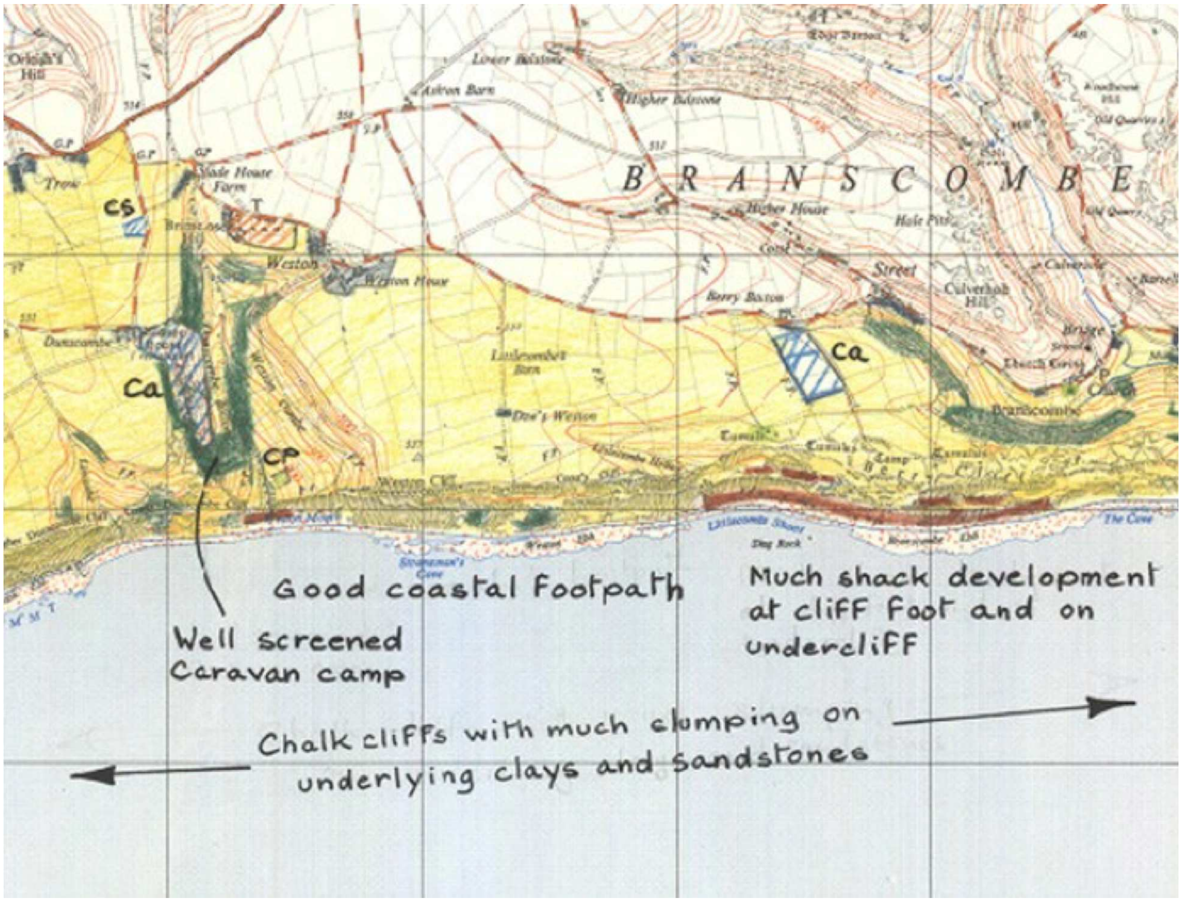
Figure 2. Different representations of woodland (coniferous and broadleaved) from different UK land cover maps a) 2007, b) 2000, c) 1990 and d) context from OpenStreetMap

Figure 3 a) the original 1965 vector layer with modern aerial photography from Bing, b) the updated vector layer with OS topographic basemap (© Crown Copyright and Database Right 2014, Ordnance Survey (Digimap Licence)), and c) the class legend used in this and subsequent figures.

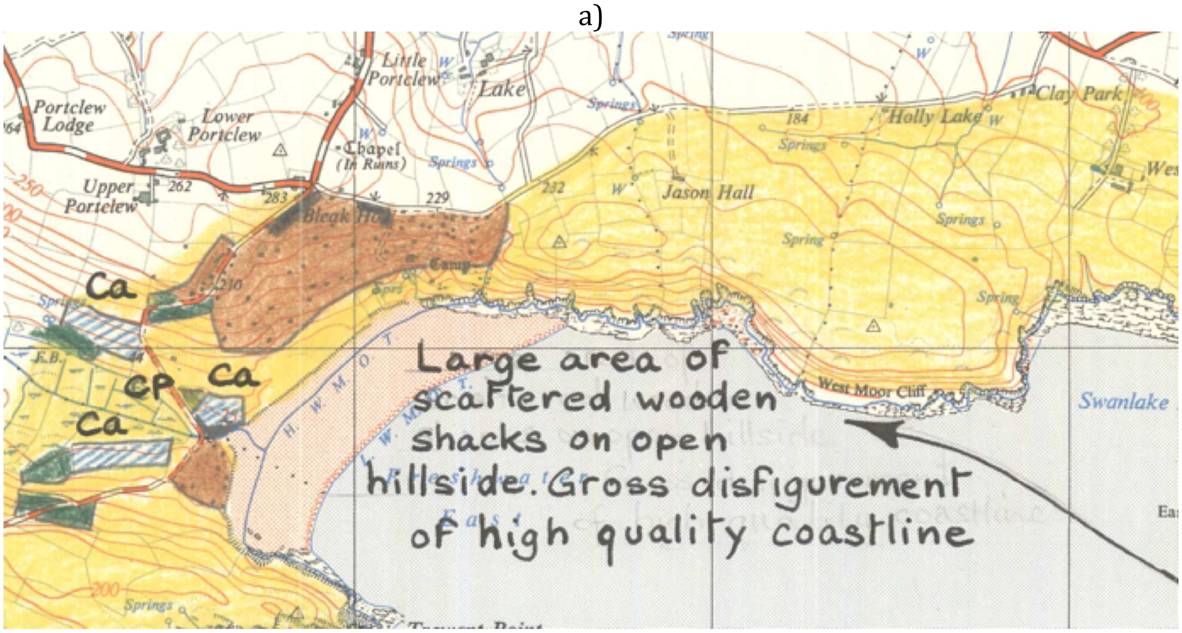
Figure 4. An example of inconsistent boundary treatment a) with OS topographic data (© Crown Copyright and Database Right 2014, Ordnance Survey (Digimap Licence)), and b) with Bing data from the OpenLayers plugin.

Figure 5: Example of errors in 1965 data, a) the original survey omitted numerous villages, a golf course and other features, and b) in the update these errors are flagged and mapped in red.

Figure 6. A cartogram of coastal land use change, with the hexagon size indicating the proportion of land use change, and the associated transformation graticule.



a)



b)

Figure 1. An example of the annotated Neptune coastal land use survey map sheets a) for Branscombe on the South Devon coast, and b) the Pembrokeshire coast.

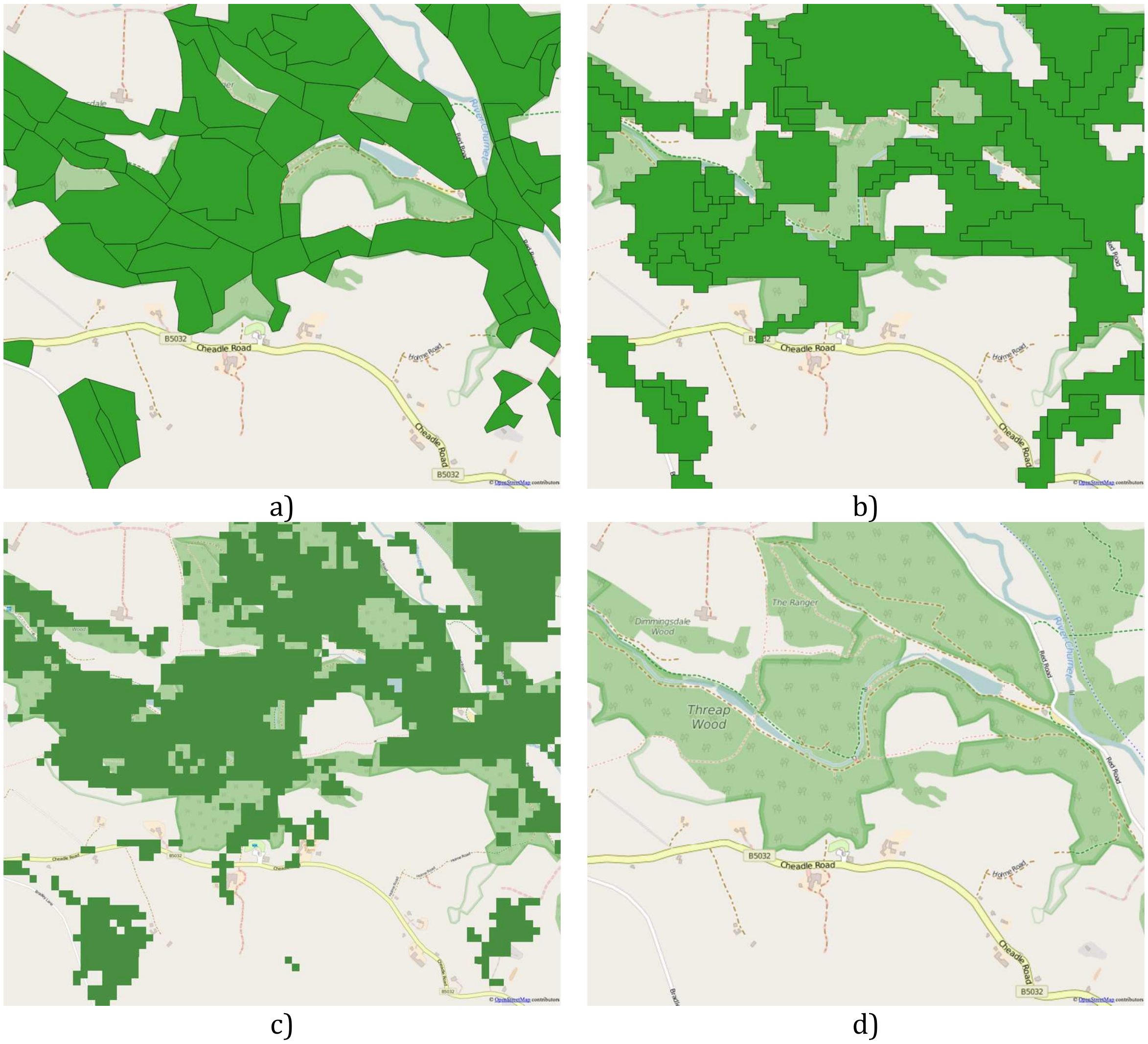
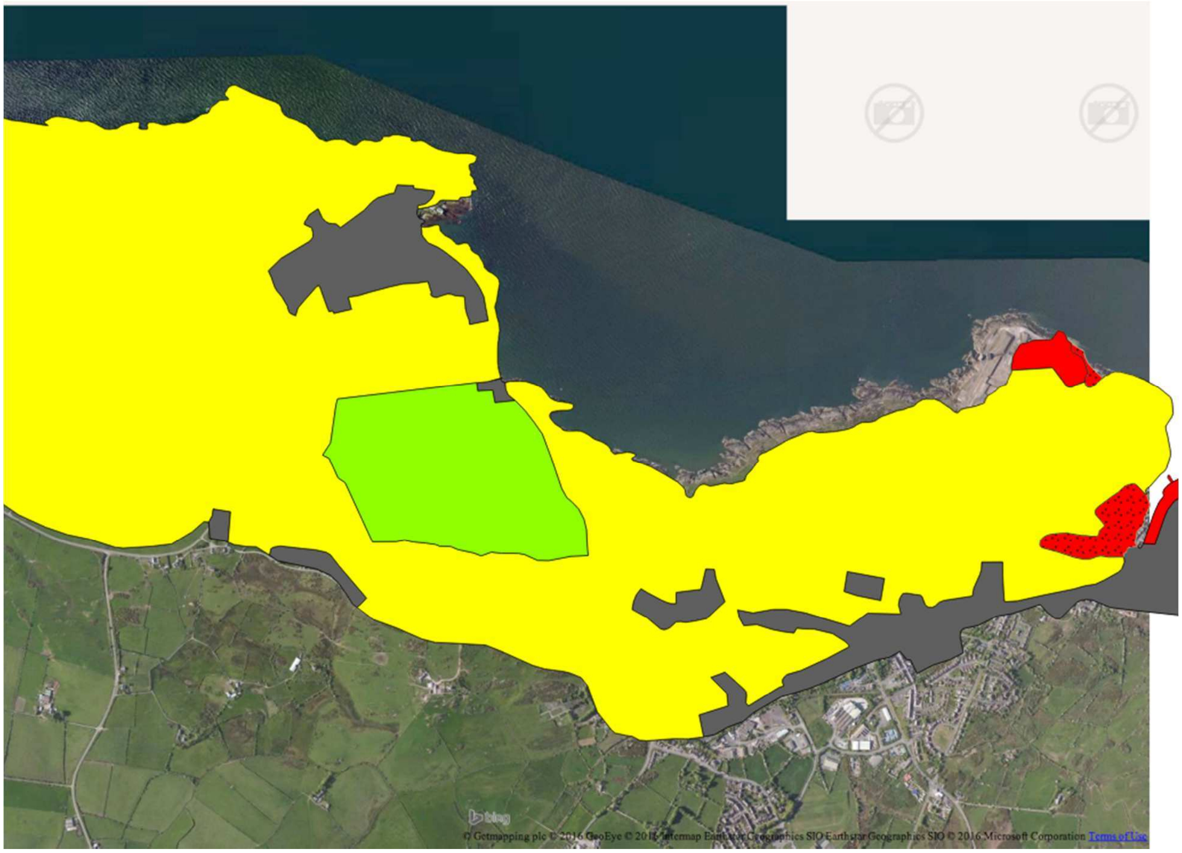


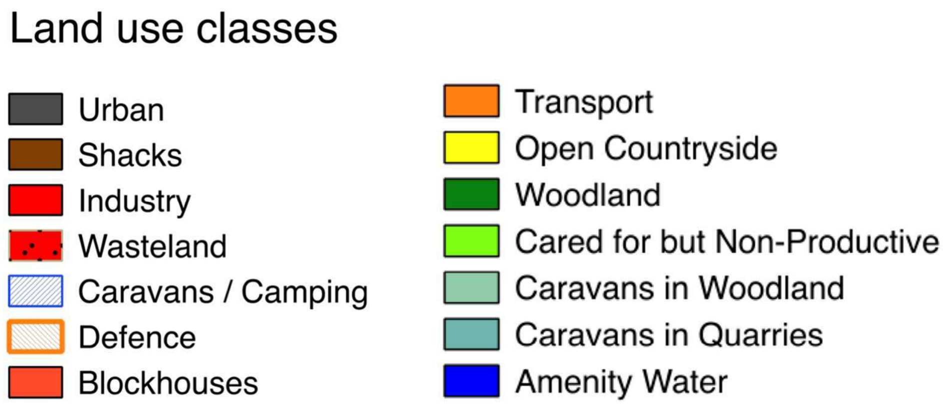
Figure 2. Different representations of woodland (coniferous and broadleaved) from different UK land cover maps a) 2007, b) 2000, c) 1990 and d) context from OpenStreetMap



a)

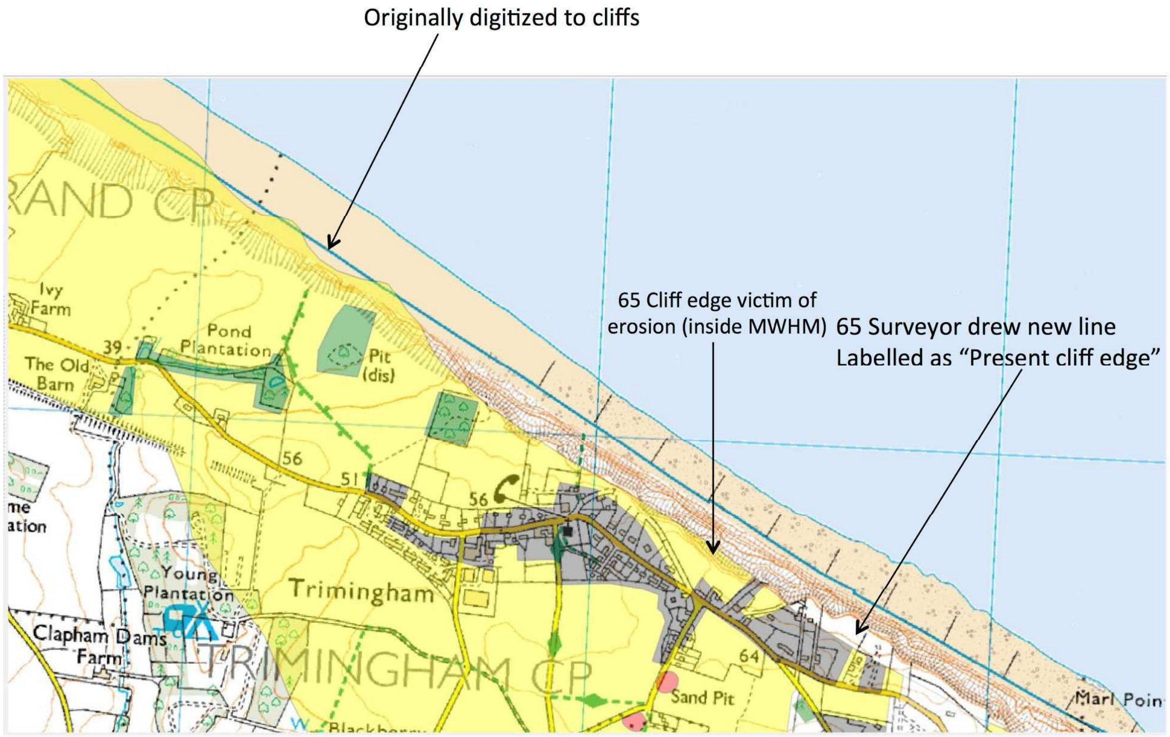

Allt Ebolion
Trwyn Myn
Ogof Gaseg
Ogof Goch
Hotel
East Mouse/ Ynys Amlwch
Bull Bay/ Porth Llechog
Trwyn Costog
Garreg Long
Garreg Costog
Porth Offeiriad
Y Crochan
Pwll y Tarw
Cave
Traeth Dynion
I o A C Path
Graig-ddu
Pwll y Merched
Burwen-fawr
Standing Stone
Bryn Llwyd
Tyddyn Barma
Llywarch
Llechog-uchaf
Plas Candryll
FB
Trogog isaf
B5111
AMLWCH
Madyn Farm
Garreg-y-Fran
Bod-Ednyfed-bach

b)

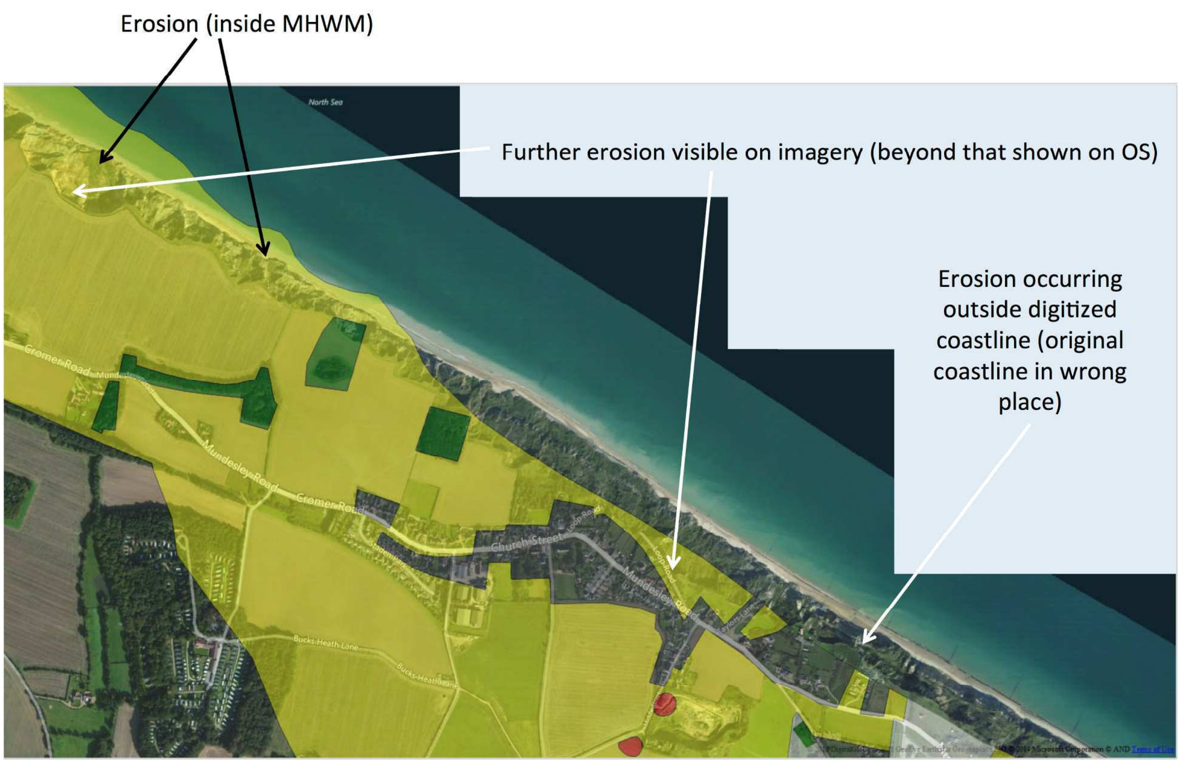


c)

Figure 3 a) the original 1965 vector layer with modern aerial photography from Bing, b) the updated vector layer with OS topographic basemap (© Crown Copyright and Database Right 2014, Ordnance Survey (Digimap Licence)), and c) the class legend used in this and subsequent figures.

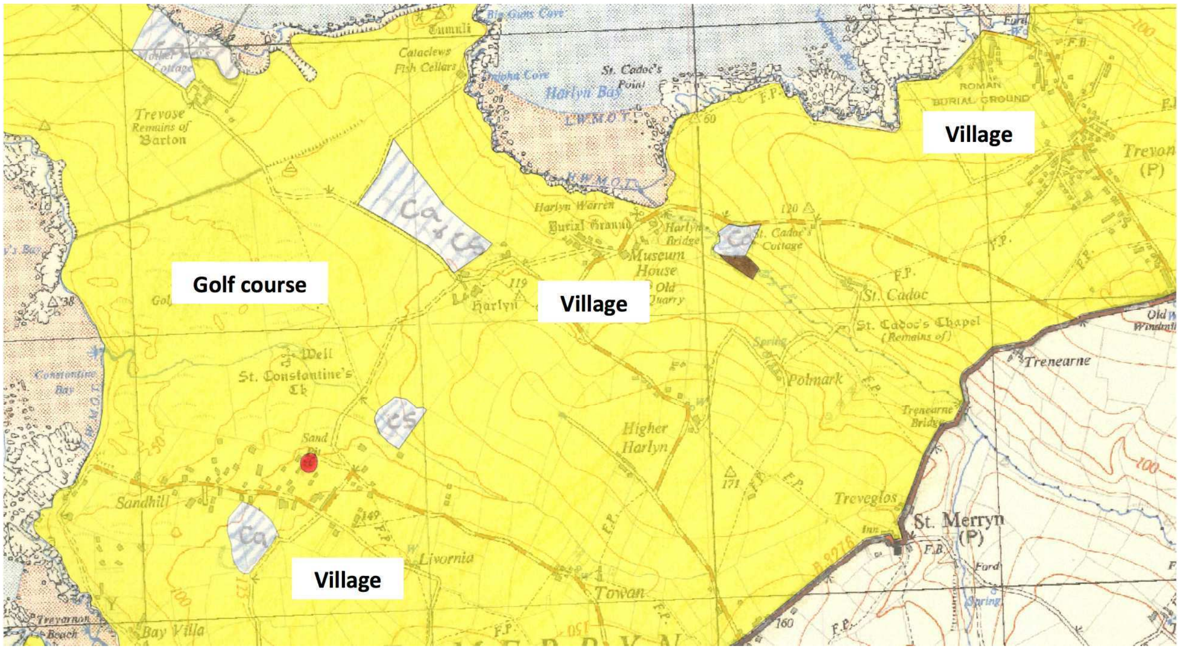


a)

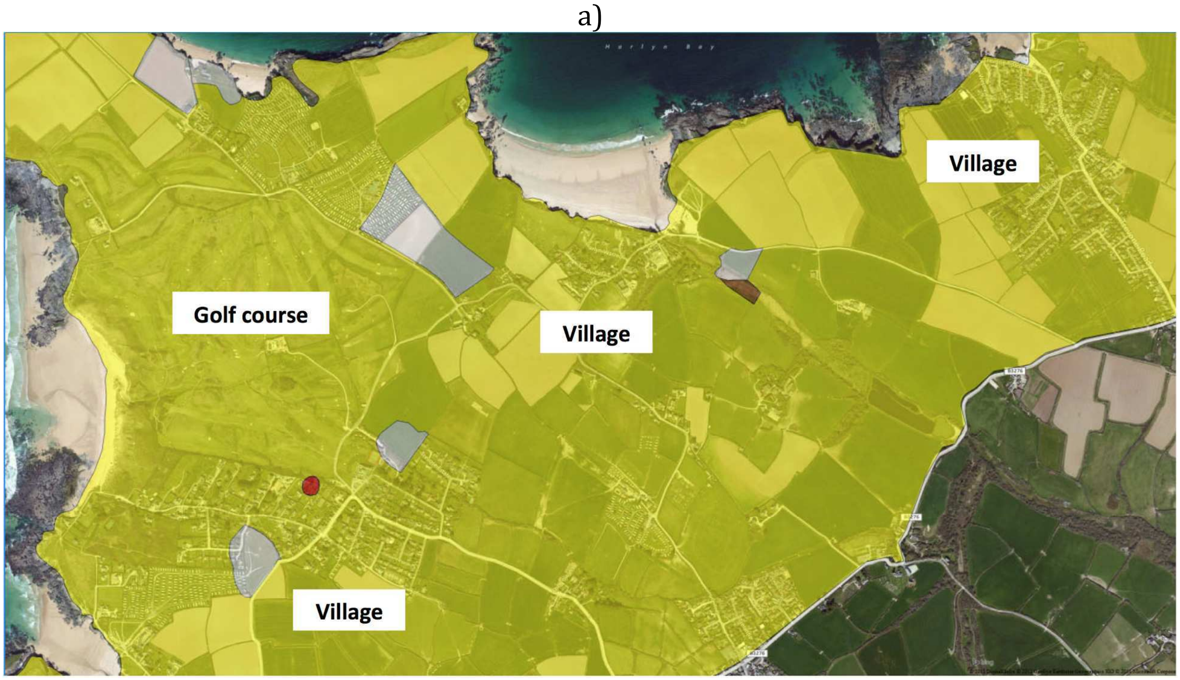


b)

Figure 4. An example of inconsistent boundary treatment a) with OS topographic data (© Crown Copyright and Database Right 2014, Ordnance Survey (Digimap Licence)), and b) with Bing data from the OpenLayers plugin.


Village
Golf course
Village
Village
Trevose
Remains of
Barton
Cataclews
Fish Cellars
St. Cadoc's
Point
Harlyn Bay
ROMAN
BURIAL GROUND
Harlyn
Museum
House
St. Cadoc
St. Cadoc's Chapel
(Remains of)
Trenearne
Polmark
Higher
Harlyn
Treveglos
St. Merryn
(P)
Well
St. Constantine's
Ck
Sandhill
Livornia
Towan
Bay Villa

a)


Village
Golf course
Village
Village

b)

c)

Figure 5: Example of errors in 1965 data, a) the original survey omitted numerous villages, a golf course and other features, b) that are evident today, and c) in the update these errors are flagged and mapped in red.

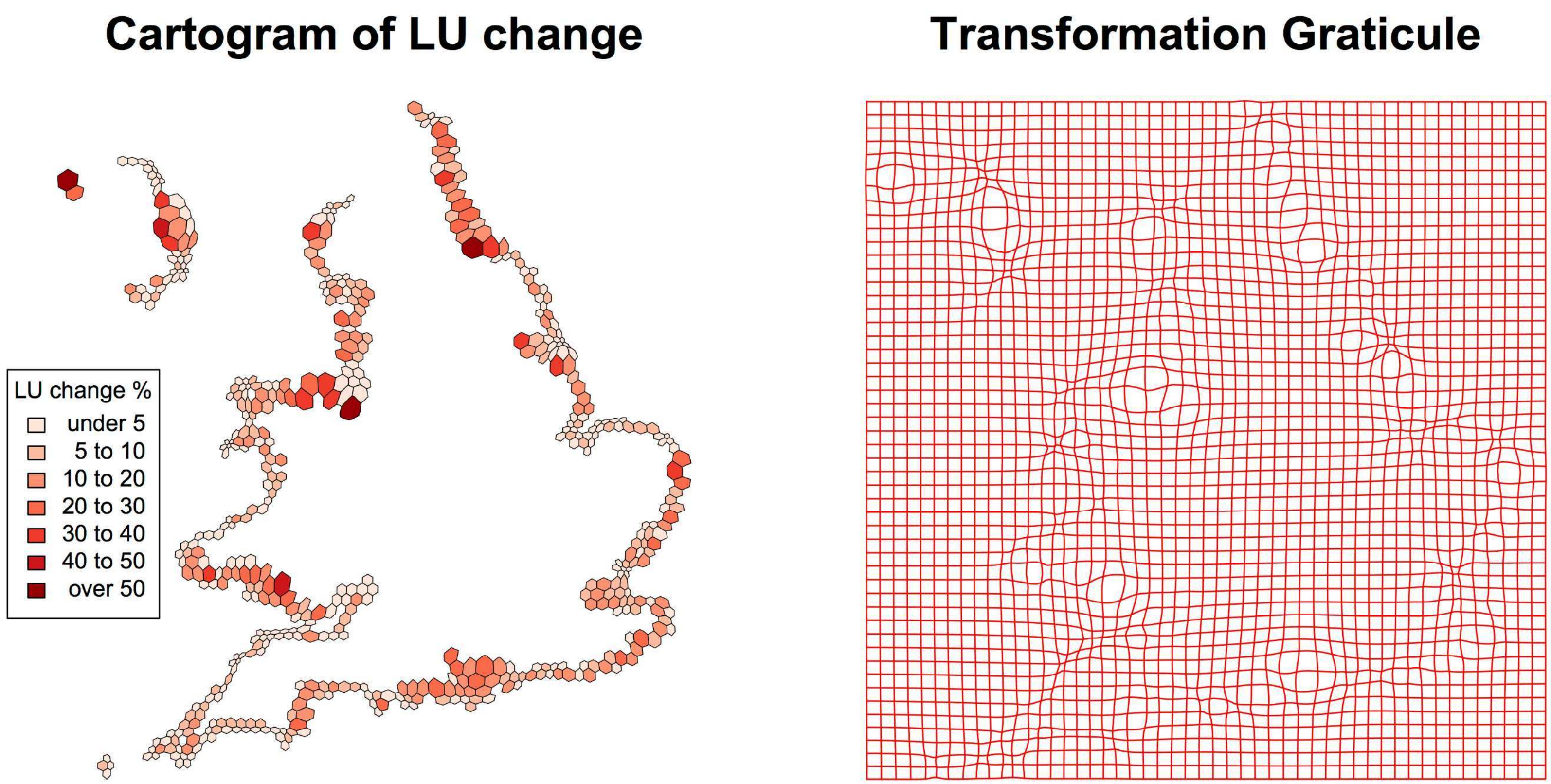


Figure 6. A cartogram of coastal land use change, with the hexagon size indicating the proportion of land use change, and the associated transformation graticule.