

Saltmarsh mapping standardisation for the Water Framework Directive



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CONTENTS

SALTMARSH MAPPING STANDARD	3
1 INTRODUCTION	3
2 DATA QUALITY AND SKILL REQUIREMENTS FOR SALTMARSH EXTENT AND COMMUNITY MAPPING FROM AERIAL PHOTOGRAPHY	4
2.1 KEY CONSIDERATIONS	4
2.1.1 <i>Planning and specification considerations</i>	4
2.1.2 <i>Quality of the photography</i>	5
2.1.3 <i>Seasonal and developmental considerations</i>	5
2.1.4 <i>Interpreter bias</i>	7
2.2 SKILL LEVEL REQUIREMENTS	7
3 SALTMARSH EXTENT MAPPING	7
3.1 GROUND DATA COLLECTION AND USE	8
3.2 SEMI-AUTOMATED EXTENT MAPPING.....	8
3.3 MANUAL EXTENT MAPPING	9
3.4 UPDATE MAPPING	9
4 SALTMARSH COMMUNITY MAPPING USING POINT CLASSIFICATION	11
4.1 CLASSIFICATION UNCERTAINTY.....	11
4.1.1 <i>Remapping and uncertainty</i>	14
5 REFERENCES	15
6 APPENDICES	16
6.1 EXTENT MAPPING IN ENGLAND AND WALES.....	16
6.2 ENVIRONMENT AGENCY PROCESS FOR SEMI-AUTOMATED MAPPING.....	17
6.3 ENVIRONMENT AGENCY PROCESSES FOR SALTMARSH ZONATION MAPPING	19
6.4 RATIONALE FOR USING A POINT CLASSIFICATION APPROACH FOR ZONATION MAPPING BY THE ENVIRONMENT AGENCY	20
6.4.1 <i>Comparison of classification recording methods</i>	22
6.5 DEVELOPMENT WORK FOR UNCERTAINTY IN PHOTOINTERPRETATION.	30
6.6 GROUND DATA FOR ZONATION WORK IN ENGLAND AND WALES	33
6.7 ZONATION AGGREGATION OF INFORMATION.....	34
6.8 GLOSSARY	36

Saltmarsh mapping standard

1 Introduction

Saltmarsh mapping has been taking place periodically throughout the UK for a number of decades for multiple reporting requirements, including Biodiversity Action Plans, Sites of Special Scientific Interest, Habitats and Birds Directives sites and more recently the Water Framework Directive(WFD). Saltmarsh is also an important consideration for flood risk and coastal management, reducing the construction and maintenance costs of sea defences when in appropriate quantity and form (King and Lester 1995, Möller et al. 1999, Möller et al. 2003). Accurate calculation of saltmarsh extent and type has therefore become an important measurement for coastal management and assessment.

Standardising the approach to mapping saltmarsh ensures consistent and comparable results. Standardisation ensures that outputs can be scrutinised objectively with an informed knowledge of the processes used to generate them. These considerations have considerable importance for the WFD, where statistics from mapping outputs are used to inform Good Ecological Status (GES).

The methods described in this document were developed to specifically satisfy the saltmarsh monitoring requirements of the WFD for the Environment Agency. The methods have been developed by the Environment Agency's Geomatics and Marine Monitoring Service and aim to represent best practice for WFD requirements in England and Wales. This document was originally requested by the steering group for the Saltmarsh Inventory of England and Wales 2006-2009 comprising the Environment Agency, Natural England, The Joint Nature Conservation Committee, and the Countryside Council for Wales.

Saltmarsh extent mapping is a relatively straight forward process with key considerations being how saltmarsh and its boundaries are defined, the data quality and the chosen creek width for mapping. Community mapping however is more complex, with a number of different classification systems in existence e.g. the Integrated Habitat System (IHS ©) or the National Vegetation Classification (NVC) system, which may or may not suit the specific objective of the task at hand. Interpreter bias is a very important consideration in community mapping with decision-making being considerably more complex than extent mapping.

In finding a suitable community mapping approach for WFD, a number of options were considered. The zonation approach which was finally chosen attempts to balance simplicity and consistency with the requirements of the directive, while minimising and highlighting as much as possible the sources and potential for error.

It is important that the uncertainties underlying the creation of mapping outputs are available to future users. Also to be as streamlined as possible and to eliminate multiple conflicting versions, one basic agreed baseline of saltmarsh extent should be created for a given aerial photography capture across organisations. A single baseline can then be used as a starting point for other mapping projects.

It should be noted that the purpose of much of the work informing this standard was to provide the necessary information for a WFD compliant classification tool and therefore will not necessarily be suited to other mapping requirements. This tool was initially developed based on current theory and published results with a focus on habitat extent, zonation and taxa diversity (Best et al. 2007).

2 Data quality and skill requirements for saltmarsh extent and community mapping from aerial photography

Digital aerial photography is used widely for cost effective fine scale mapping for different land cover scenarios, including natural and semi-natural habitats. It is an effective resource for the mapping of saltmarsh extent and communities with the appropriate levels of consideration during data capture and interpretation. Figure 1 shows a broad flow of the process of saltmarsh extent mapping from flight planning through to the final extent map.

The validity of photographic interpretation outputs depends upon a wide variety of factors. Photographic interpretation is not an exact science and there are many potential sources of error. Sources of error should be properly understood before using the output classifications in further analysis or reporting statistics generated from them.

2.1 Key considerations

2.1.1 Planning and specification considerations

Aerial photographic image capture for saltmarsh should, as a general rule, be:

- a) during summer months, between June and September. Flights could be as early as May in some cases.
- b) in conditions free from cloud and cloud shadow.
- c) when the sun angle is greater than 20 degrees.
- d) with tidal constraints factoring in when the entire saltmarsh is exposed.

For these reasons it is important that flights are planned carefully to capture data in the windows available. Image ground sample distance or resolution should be between 10 and 25 cm to provide a balance of sufficient detail to

interpret the imagery and efficiency in data capture. Finer resolution data will cost significantly more without there necessarily being a corresponding additional benefit. Lower resolution imagery can support saltmarsh extent mapping however this will be with reduced confidence.

For any vegetation mapping, 4-band full colour/near-infrared (NIR) photography will have some benefit. NIR data capture is generally cost efficient and presents added benefits where automation of mapping tasks is taking place.

Light detection and ranging (LiDAR) is an airborne remote sensing technique using lasers to obtain information on the location and height of features on the ground. LiDAR provides useful supporting information on saltmarsh extent and communities however should ideally not be used as the primary source of data for either extent or community mapping.

2.1.2 Quality of the photography

Quality and consistency will not be common between photography data that has been captured on different days, times of day, or with different camera systems. The issue of timing relates mainly to the variation in lighting conditions, either due to sun elevation or atmospheric effects such as haze, water vapour or very thin high altitude clouds.

In addition, the techniques used to process photography depend on a significant amount of human input, especially during the colour balancing stage of processing. This means that for each project there is likely to be a unique contrast and brightness stretch applied to the data.

All of these factors can make the appearance of specific vegetation types inconsistent between different sets of image data. This means that interpreters will not necessarily be able to apply their knowledge in a consistent manner and recognition of the same vegetation may vary across differing image outputs.

2.1.3 Seasonal and developmental considerations

Other factors affecting the appearance of certain vegetation types are the time of year and stage of phytological development. This can have a serious impact on the appearance of the vegetation in aerial photography and is especially relevant during the period when saltmarsh plants flower.

Photography data of the same area of saltmarsh acquired at the same time and on the same date, but in different years is likely to show variation due to fluctuations in vegetation development across seasons in different years. Development will also be influenced by geographic location, due partially to climatic variations, so saltmarsh in the north of England is likely to develop at a different rate to saltmarsh further south. Monitoring in July and August is preferable, with the months adjacent to these (June and September) being less ideal. The month of May is the least preferable of those recommended for image data capture.

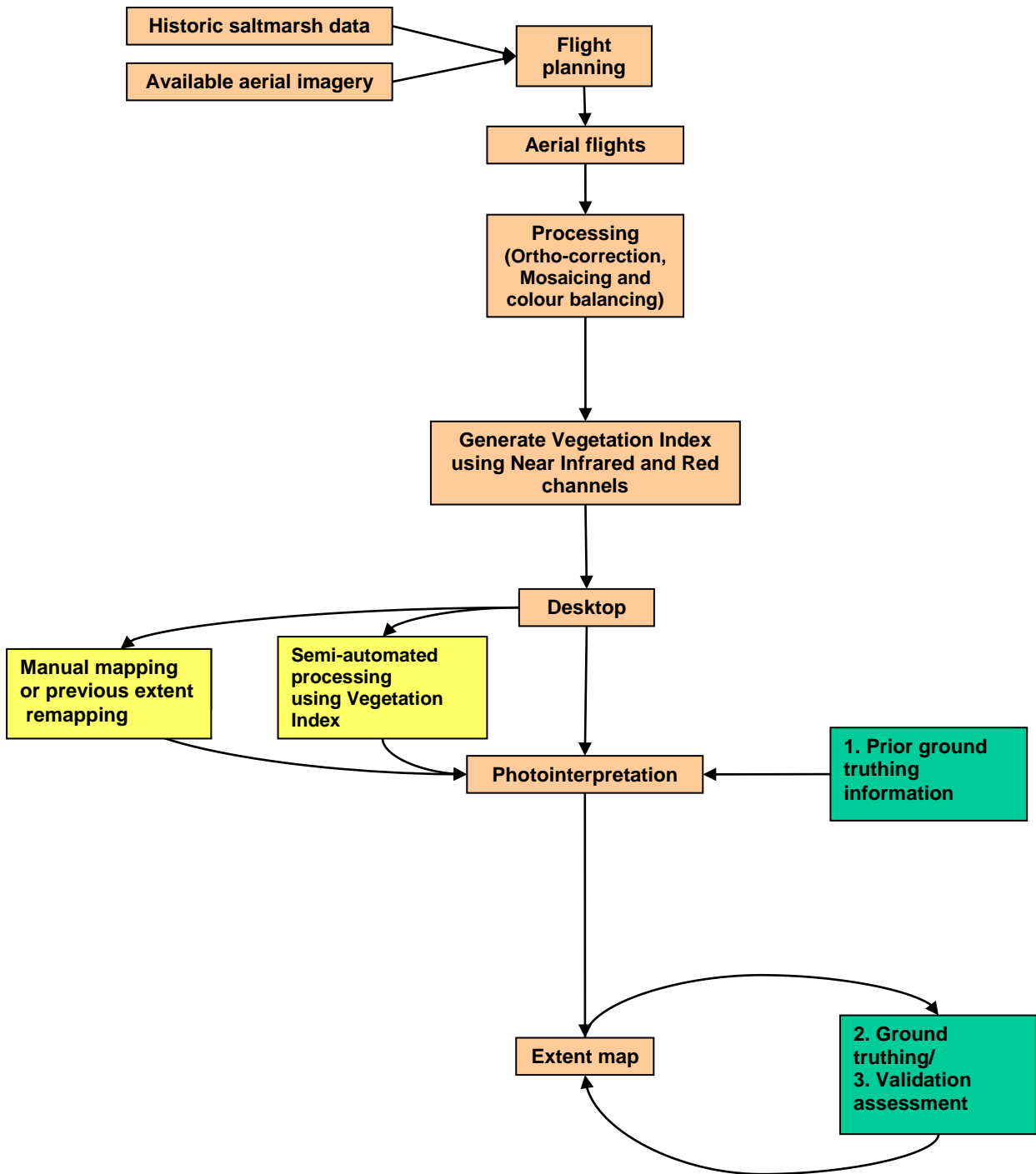


Figure 1. Flow chart showing the major steps taken in deriving saltmarsh extent maps from aerial photography

Extent mapping approaches

Ground truthing approaches

2.1.4 *Interpreter bias*

Outputs from photo interpretation, as with all remote sensing techniques, will not be one hundred percent accurate. It is accepted in image interpretation that no two interpretations will be exactly the same, especially when comparing interpretations undertaken by two or more people. Therefore it is important to understand the level of confidence one can have in an interpreted map. Some understanding of this can be achieved by examining the differences between multiple interpretations of the same location. Variability across interpretations can allow a factoring in for confidence of products with similar photointerpretation conditions. These limitations can to a certain extent be mitigated by an increased volume of quality ground data. Certain types of saltmarsh will naturally provide less scope for error, for example where there are no pioneer zones or terrestrial transitions.

2.2 Skill Level requirements

Extent processors should have the following skills:

- a) Good operational experience of GIS databases along with a knowledge of potential sources of human error from using the chosen GIS platform.
- b) Good understanding of saltmarsh ecology including saltmarsh field experience.
- c) Good understanding of the limitations of image interpretation, including the processes and data sets being used with specific aerial image interpretation experience.

Those undertaking saltmarsh community/zonation mapping should additionally have undergone a considerable period of training and supervision to achieve a level of satisfactory capability. Training should be focussed on identifying the required saltmarsh communities under varying lighting, seasonal and quality conditions. A significant period of supervision for mapping should follow all training with continuous improvement processes built in to all approaches employed.

3 Saltmarsh extent mapping

Two broad methods have been applied to saltmarsh extent mapping using aerial photography; semi- automated and manual digitisation. The two methods have benefits and disadvantages. Done correctly however, the two mapping outputs should produce comparable results.

In most cases of update mapping, a manual remapping approach using the previous mapping output (baseline editing) is preferable to:

- a) reduce inconsistencies from differences in independent mapping outputs,
- b) provide the context for what was previously identified as saltmarsh,
- c) reduce the effort required in remapping.

For both manual and semi-automated mapping, minimum creek width for mapping should be a built in consideration.

A broad outline of the workflow involved in aerial photography mapping from flight planning to a ground truthed extent map is outlined in Figure 1. An approach to aid in creek width standardisation which can be undertaken after either manual or semi-automated mapping is described in Appendix 6.2. The creek width mapping cut-off employed by the Environment Agency is 2m, meaning a creek will no longer be mapped when its width is less than this. Creeks less than 2m will therefore be included in the saltmarsh area estimate.

3.1 Ground data collection and use

Where possible, ground data consisting of points that coincide with the landward and frontal edge of the saltmarsh should be collected, particularly in areas which are perceived to generate difficulties in the mapping process. Collection should occur as close as possible in time to the aerial image capture, so that any seasonal variations in extent do not confuse the information/validation. Recommended months for ground data collection will be between June and September. In some regions ground data collection could be as early as May.

Ground data can be used to inform the interpretation of the position of the saltmarsh and to provide a measure of the confidence in the interpretation. A measure of distance error can be generated to inform this. Root Mean Square Error (RMSE) is a standard measurement of error in spatial sciences and is an appropriate statistic to provide a measure of the confidence in interpretation. This provides a measure that states what distance 66.6% (equivalent of one standard deviation) of the data points are within from the interpreted boundaries. Differential GPS would be appropriate for this if available; the RMSE value would be deemed not significant if it was lower than the accuracy of the differential GPS data.

3.2 Semi-automated extent mapping

The semi-automated mapping method for first time mapping can strike a good compromise between efficiency and accuracy. In addition to the basic interpretation knowledge requirements, there should also be knowledge of spectral classification and a handling of large raster and vector datasets. A description of the Environment Agency methodology is summarised in

Appendix 6.2 and, where it fits in the overall process can be seen diagrammatically in Figure 1.

Benefits of semi-automated extent mapping

- Cost effective
- Repeatable
- Simple, standardised methodology
- Most processing can be done within the standard GIS environment
- 20 cm photography adequate

Disadvantages of semi-automated extent mapping

- NIR data required (should not add cost onto data capture nowadays)
- Relies on photosynthetic vegetation to work. Manual intervention required otherwise
- Potential for inconsistency in outputs from different interpreters
- Potential for noise when comparing multiple outputs

3.3 Manual extent mapping

The manual digitizing method for first time mapping can produce a smoother output because it is not based upon pixel classifications. However, it can also be time consuming, especially in areas of high fragmentation, even for update mapping. A typical methodology is summarized below.

- Image data displayed on-screen within GIS environment.
- Image data displayed at a standard scale to ensure consistent level of detail in mapping output.
- Boundary of saltmarsh units digitized either by using a digitising tablet or an on-screen pen display applying creek width, external and internal fragment mapping rules as set out. Environment Agency criteria can be seen in Appendix 6.1 Extent mapping in England and Wales6.1.

Benefits of manual extent mapping

- Smooth outlines
- QA process may be incorporated into digitising
- NIR data not necessary

Disadvantages of manual extent mapping

- Time consuming
- More potential for inconsistency in outputs between different interpreters than semi-automated approach
- Fragmented marsh may take a long time to map

3.4 Update mapping

There are two approaches to update mapping that could be applied, depending on how much change there is or how fragmented the saltmarsh is.

In general for consistency it is preferable to manually edit the baseline saltmarsh (“baseline editing”). In cases where there is significant complex change, or change within a highly fragmented area of saltmarsh, it may be appropriate to apply the semi-automated method to these sections of the saltmarsh.

Scanning the imagery to look for areas of change is undertaken with attention paid to the onscreen scale e.g. Environment Agency scanning will be at 1:1000. Where manual edits are undertaken, the digitizing process is applied at a finer scale. The Environment Agency remapping will generally take place at a scale of 1:500.

There are benefits and disadvantages to both baseline editing. These are outlined below:

Benefits of Baseline editing

- Quick method for recording change
- Consistent results that minimise false change
- Normally does not require using 4 band imagery

Disadvantages of Baseline editing

- Inappropriate for complex areas of change

Using automations to remap may be appropriate for areas of great/complex change however there is greater potential for false change to be recorded due to inconsistent mapping form/technique between years.

4 Saltmarsh community mapping using point classification

Community mapping presents a number of difficulties in terms of consistency of judgement and boundary delineation which are discussed in detail in this section.

The work below has been driven by the WFD metric requirements for saltmarsh with zonation metric for England and Wales assuming a fully functioning saltmarsh will have all major zones in balance. The number of zones will vary on a number of factors, including the bio-geographical region and geomorphological constraints. In England and Wales five functional zones have been outlined:

- Pioneer: *Salicornia* and pioneer species
- *Spartina* dominant marsh
- Mid-Low marsh mix (*Atriplex*, *Puccinellia*)
- High marsh (*Festuca rubra*, *Elytrygia* dominant marsh, *Bolboschoenus*, *Juncus* dominant marsh).
- Reedbeds (*Phragmites*)

An elaboration of this classification system can be seen in Appendix 6.7. There are two different saltmarsh zonation mapping techniques that can generally be employed. The first is a digitising technique and the second is a point sampling technique. These methods were compared by the Environment Agency prior to choosing an appropriate WFD method with a justification for choosing the point classification approach given in Appendix 6.3 and 6.4. The development of a zonation mapping approach was originally detailed by Hambidge et al. (2012). This approach has recently been adopted by the Environment Agency and Natural Resources Wales for WFD classification, and more recently by Natural England for saltmarsh zone interpretation.

Irrespective of method used, ground data is integral to the plant community classification informing photointerpretation. This may be in the form of quadrat data, saltmarsh transition data or basic community confirmation. Interpreted zonation information should be cross referenced with ground data in areas of low confidence. The benefit of taking ground data after an interpretation has been produced is that areas of low confidence can be targeted. This can be highlighted through classification uncertainty techniques which are described below.

4.1 Classification uncertainty

The variations in interpretations are partially due to the interpreters' uncertainty as to exactly where boundaries between habitats lie. These may be because of inconsistent image data, errors in the transects or inexperience on the part of the interpreter. In some cases the interpreter has high certainty that a particular area belongs to a certain class. However, there will be areas

where this certainty is greatly reduced, sometimes to the point where the interpreter believes that the area could potentially occupy one of several classes. This uncertainty can be the product of two main issues. The first and most obvious is the uncertainty in the interpreter, partially due to inexperience, either generally or due to a specific factor such as unfamiliar lighting conditions, geographic extent or time of year. However, another issue is that the boundary between classes may be a gradual transition creating ecotones (Figure 3), rather than a hard boundary where the class suddenly changes from one to another. Within the ecotone there will be more than one class present, so there will be uncertainty as to which class is most appropriate.

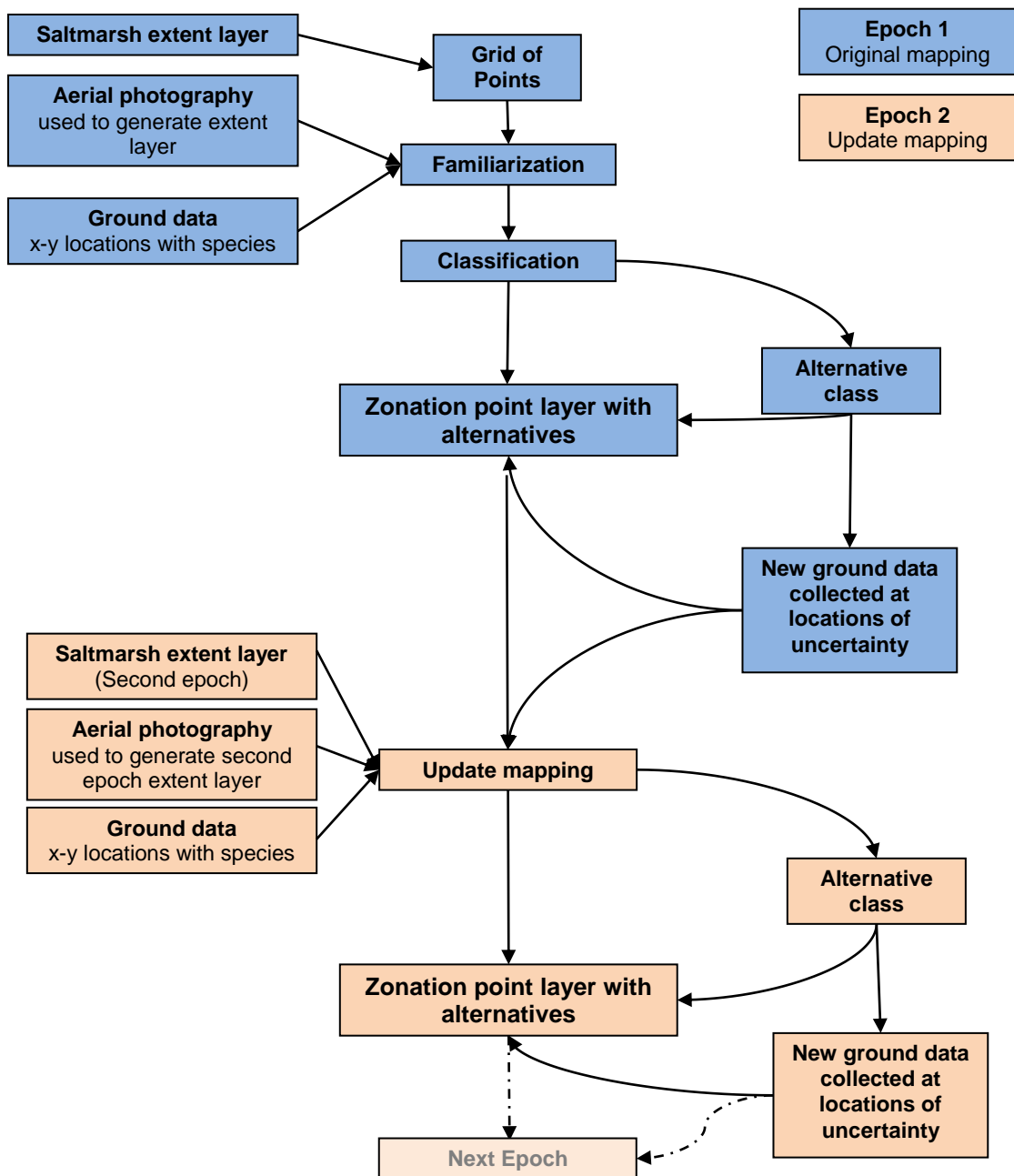


Figure 2. Major steps taken in deriving saltmarsh community maps from aerial photography.

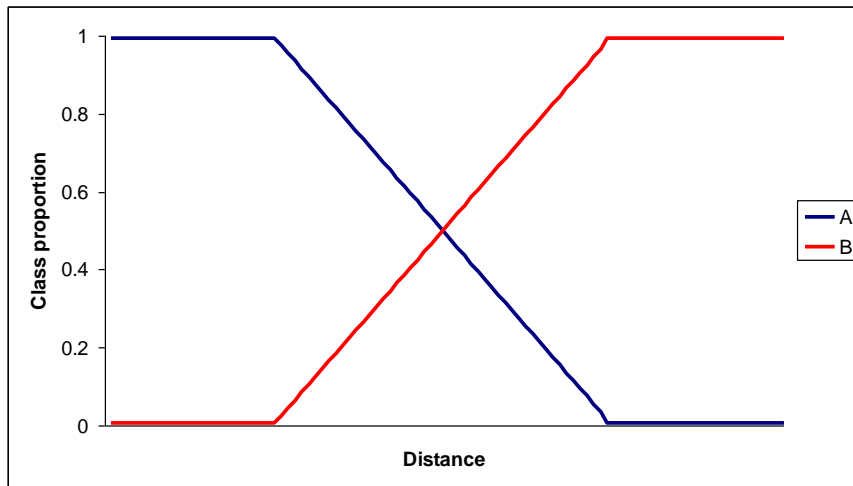


Figure 3. Simplistic example of an ecotone with 2 classes, A and B.

When drawing a boundary the ideal position would be where each habitat type makes up 50% of the cover, but this is difficult to do on the ground, let alone from data acquired at 1000m above ground level.

The form of mapping where a point can only belong to one class is called 'hard' mapping. Not only does hard mapping not represent the uncertainty in the interpreters mind, it does not necessarily represent reality. If, when an interpreter maps a boundary, that boundary is contained within an ecotone, one could interpret the map to be correct. However, it is unlikely that two interpreters will map the boundary in the same way, i.e. the position of the line through the ecotone will vary (Figure 4b and Figure 4c). This would result in an error when data are compared (Figure 4d).

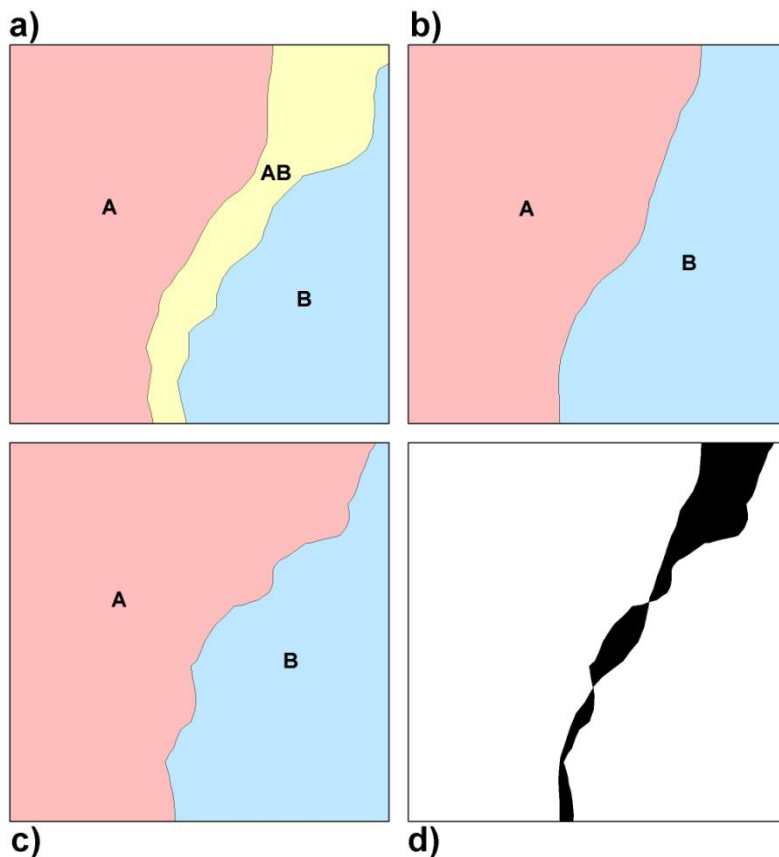


Figure 4. Hard interpretations of the same reality. a) Actual ground classes A and B, with ecotone (AB) between them (yellow). b) One photo-interpreter's map. c) Another interpreter's map output. d) Areas of difference between interpretation in black.

4.1.1 Remapping and uncertainty

In future years where repeat mapping has taken place, areas which show change should be scrutinized by the interpreter to assess whether real change is taking place or whether the change is due to misinterpretation. In those areas where it is likely to be due to misinterpretation from the first classification, it should be edited to the more appropriate class. The process of mapping real change can then begin.

In areas where there is doubt, the interpreter should assign the most likely class to the points, and flag them up for revisiting later in the mapping exercise, possibly once more experience has been gained in that water body, or once the area is not at the front of the interpreter's mind. This may be done by digitising a polygon around these low confidence points. When revisiting the polygons, the interpreter can assign a single alternative class. This exercise doubles up as a stage in the QA process in identifying areas of low confidence.

When re-mapping is undertaken, those areas where there is any class assignment overlap either between first choice classes and alternative classes could then be ignored as being unlikely candidates for actual

significant change. More likely is that they are changes due to either misclassification or ecotone boundary interpretation.

5 References

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6 Appendices

6.1 Extent mapping in England and Wales

The vast majority of saltmarshes in England and Wales were mapped in the 2006-2009 saltmarsh inventory for England and Wales (Phelan et al. 2011). This was undertaken by the Environment Agency (largely for Anglian, North East, North West and Welsh Regions) and by external contractors for Channel Coastal Observatory (CCO) for South East and South West Regions. In addition, many water bodies have been mapped using a second round of aerial photography by the Environment Agency and the CCO (Figure 5)

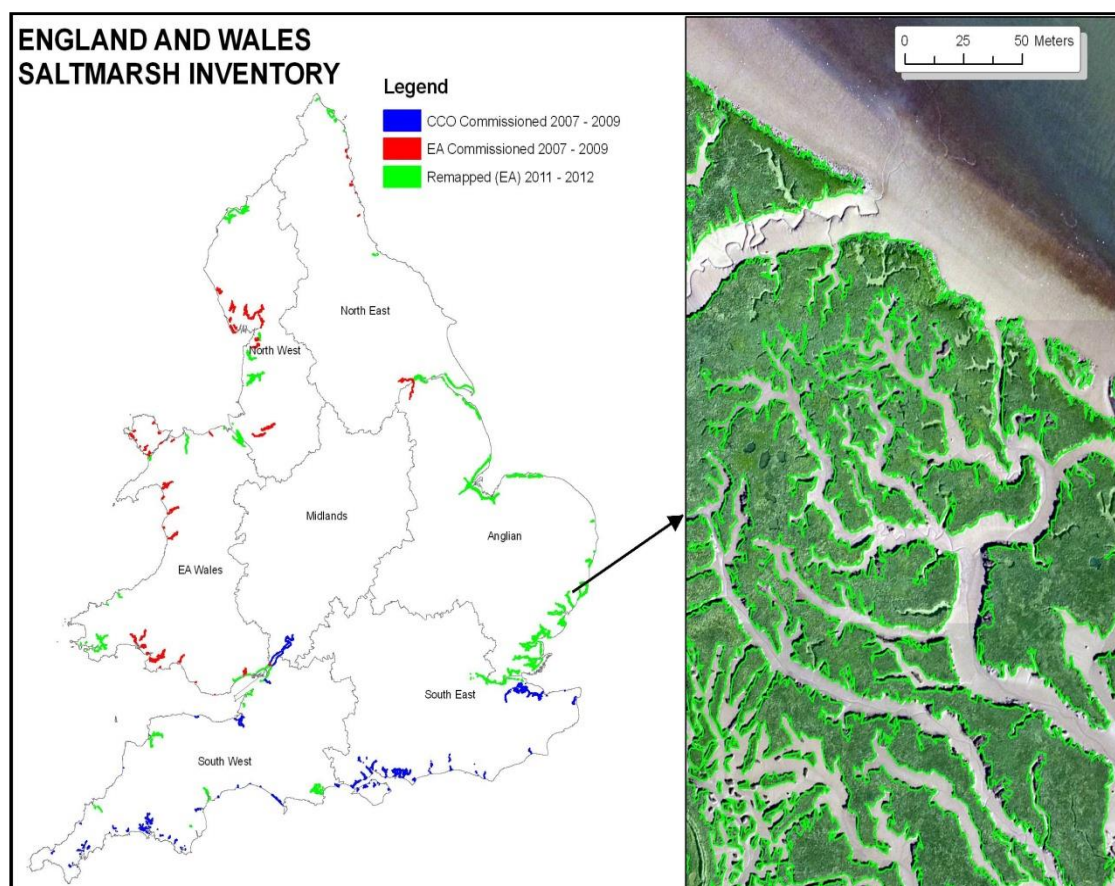


Figure 5. The spatial distribution of saltmarsh in England and Wales and how it has been mapped. CCO commissioned data was largely mapped by manual digitization and the EA mapping by semi-automated techniques. The image on the right shows a section of saltmarsh to give an idea of the level of detail it has been mapped to.

Table Table 12. Information recorded with each saltmarsh extent layer polygon.

GIS name	Actual name	Description
EA_WB_ID	WFD water body Code	WFD water body Code
WB_NAME	WFD water body Name	WFD water body Name
YEAR	Survey Year	Survey Year
MONTH	Survey Month	Survey Month
INTERPRETE	Interpreter	Name of Interpreter
INTERP_ORG	Interpreter Organisation	Organisation of Interpreter
MODIFIED_D	Modification Date	Modification Date
MOD_INTERP	Modifier	Name of modifier
MOD_ORG	Modifier Organisation	Organisation of Modifier
NIR_USED	Near Infrared Used?	Was Near Infrared Used?
AP_SOURCE	Photography Source	Photography Source
CREEK_WIDT	Minimum Creek Width	Minimum width of creek within saltmarsh
VERS_NO	Version Number	Version Number
AREA	Area m2	Area in m2

6.2 Environment Agency process for semi-automated mapping.

- An upper tidal limit mask is applied to photography data to exclude areas above Highest Astronomical Tide level. This mask should be examined carefully, so areas are not excluded due to anomalies in the dataset. In addition a water mask will exclude areas of water visible within the imagery.
- NIR channels of the 4 band photography are combined to produce a greyscale Vegetation Index image (high values are vegetation, low values are non-vegetation) which can be viewed in Figure 6b.
- Pixels within Vegetation Index are assigned to one of two classes (vegetation / non-vegetation) according to the pixel value. This is done by determining a threshold value, by eye, which best represents the vegetation within the imagery. Sometimes different thresholds need to be applied in different parts of the imagery. This is often dependent on lighting qualities/imbances within the image, or more rarely the vegetation type. This can be viewed in Figure 12c.
- Digital pixel based classification is filtered to remove clumps of vegetation smaller than 5 m² and internal areas of non-saltmarsh smaller than 150 m² (this figure was originally chosen as it was the approximate threshold that eliminated the greatest number of internal fragments from a semi-automated output).
- Filtered image is converted to vector format (Figure 6d).
- Vegetation outline is visually inspected and where appropriate edited to remove non-saltmarsh vegetation (e.g. macro algae) that may have been picked up in the original classification. In addition areas of saltmarsh that have been missed by the original classification may be added back into the classification manually.

The saltmarsh classification layer can then undergo creek width standardisation processing to dissolve any creeks picked up in the classification which are finer than 2 metres in width. This is done using a 4-step process:

1. An external buffer of 1m is applied to the classification,
2. Boundaries are dissolved,
3. An internal buffer of 1m is applied,
4. Inner areas of non-saltmarsh that are smaller than 150 m² are dissolved.

This procedure is only carried out on saltmarsh areas greater than 0.5 hectares (Ha) to ensure fragmented areas are not over classified.

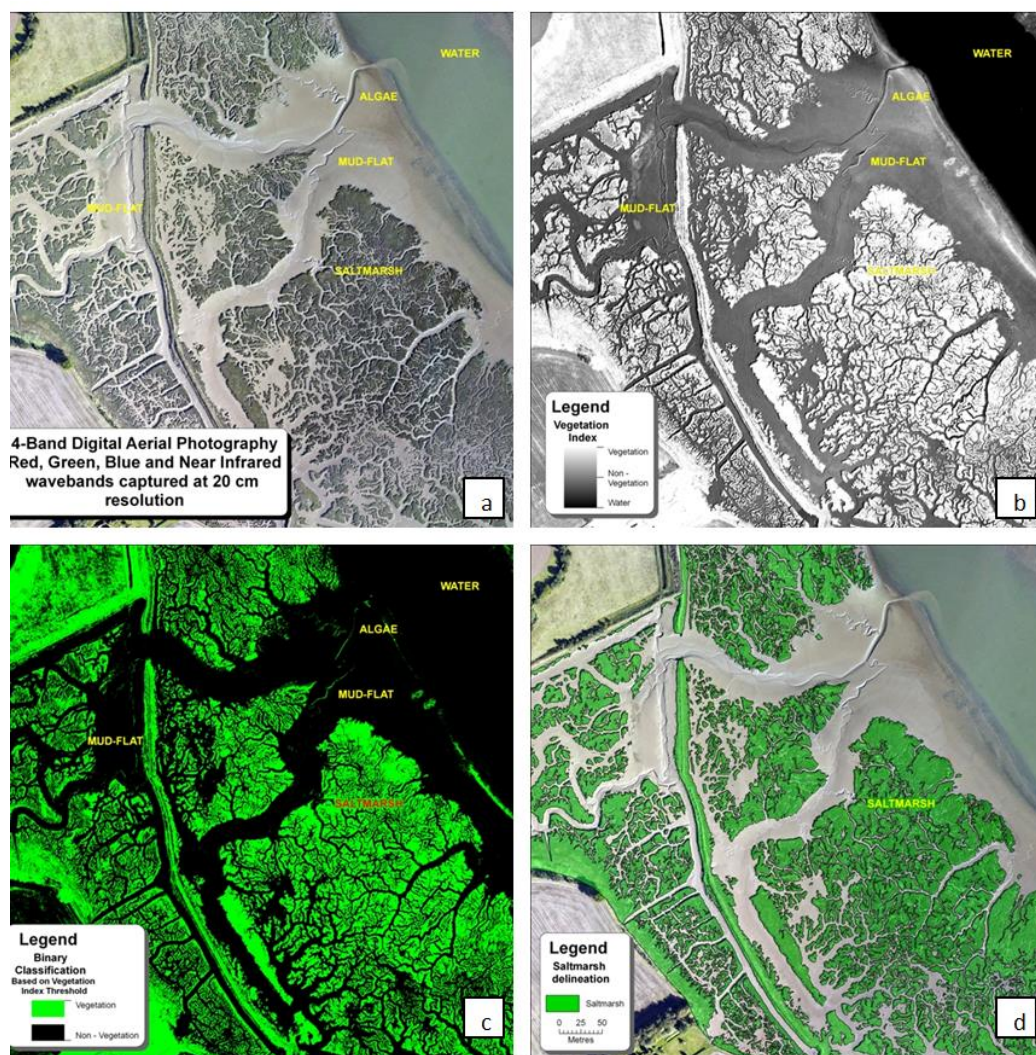


Figure 6. Different automated classification stages using aerial photography: a) colour balanced map-ready image b) grey scale vegetation index layer generated from NIR channels c) binary class where green represents vegetation and black non-vegetation, generated by applying a single threshold to the vegetation index layer in b). d) final saltmarsh extent layer

6.3 Environment Agency processes for saltmarsh zonation mapping

The mapping undertaken for saltmarsh zonation by the Environment Agency has largely been driven by WFD surveillance water body monitoring requirements. This is reflected in Figure 7. Zonation mapping in England and Wales, which also shows the areas mapped for Natural England using the same technique as that used for the Environment Agency mapping. It should be noted that a different classification system has been used in the South East and South West regions in non-Surveillance water bodies which delineates different IHS zones (i.e. does not use the point method described above).

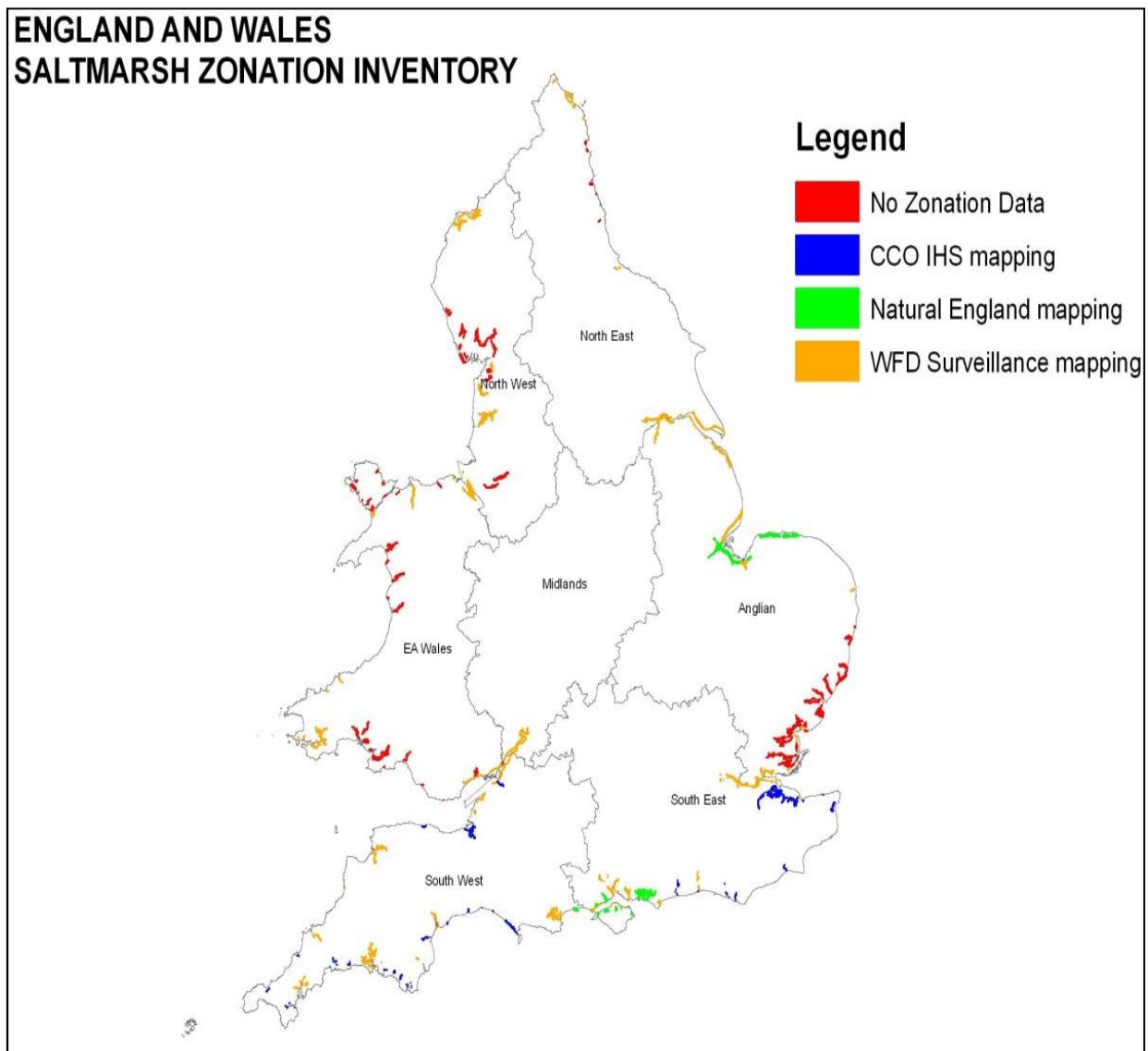


Figure 7. Zonation mapping in England and Wales

Table 3. Information recorded with each saltmarsh zonation point.

GIS name	Actual Name	Description
EA_WB_ID	WFD water body Code	WFD water body code
WB_Name	WFD water body Name	WFD water body name
Gridsize_m	Gridsize (m)	Distance between points in grid (either 5m or 10m)
Interpreter	Interpreter	Initials of interpreter
Published	Published	Date data were first published
Class	Class Code	Numeric class code indicating saltmarsh zone
Alternate	Alternative Class Code	Numeric class code for alternative zone (where there is uncertainty)
Captured	Captured	Name of company that supplied photography data and year of capture
Year	Year	Year of data capture
Classific	Class description	Description of saltmarsh zone
Alt_Class	Alternative Class	Description of alternative zone (if present)
GeoTag	GeoTag	Unique positional ID number. The first 6 digits represent the British National Grid X coordinate. The last 6 digits represent the Y coordinate.
Princ_CD	Principal Code	Indicates whether point falls within EA England jurisdiction or NRW Wales jurisdiction
REGION_NAM	Region Name	Region Name
Commision	Commissioner	Indicates whether Natural England, Environment Agency, or Natural Resources Wales commissioned

6.4 Rationale for using a point classification approach for zonation mapping by the Environment Agency

A comparison was made between the results and speed of interpreting saltmarsh zonation communities using point classification and vector mapping.

The first method involved creating a regular grid of points spaced evenly 10 metres apart and photo-interpreting each point on the grid as an alternative to manually separating out vegetation through the creation of a polygon. For the process, the Environment Agency's Geomatics team developed an intuitive tool in ArcGIS to facilitate a manual process of classifying each of the points according to the vegetation they lie on top of. To address the concern that the 10 metre spacing might be too coarse for some of the smaller water bodies, especially where saltmarsh may be more fragmented, it was proposed that a finer 5 metre point spacing grid be used in these areas. A cut-off of less than 30 Ha, representing a third of the surveillance water bodies, was used to determine those that would qualify for finer grid spacing.

The second method involves manually digitizing the boundaries between the five functional saltmarsh zones (described above). When digitising there are three decisions to make which may result in slowing the interpretation down:

1. Where is the boundary?

2. Is the block of vegetation large enough to be worth mapping?
3. What class does the block of vegetation belong to (also required in the first method)?

In addition to the above decisions, the boundary line then needs to be drawn along the perceived boundary.

The national saltmarsh extent layer was used as the template for the digitization. Polygons from this layer were split up according to where the interpreter decided a boundary lay between one class and another. This was done at an on-screen scale of 1:1000 using the "Cut Polygon Features" in ArcGIS with the aid of an on-screen digitizing tablet (Wacom Cintiq 21 UX). The scale 1:1000 was chosen as a compromise between detail visible in the image data and efficiency of digitising. The larger the scale used the more detail can be digitised, but this is at the expense of efficiency.

Using the point method, there are fewer decision processes to undergo compared to line mapping. The only key decision to make is: "what class does the vegetation that lies directly beneath a point belong to?" There is no need to decide on where a boundary lies, because the boundaries are essentially defined by the grid of points being used. Every point is mapped, so no decision needs to be made as to what the minimum mappable unit is when processing the points. The image data were viewed at the same scale as the digitizing method, 1:1000.

For this assessment, two areas in the Humber estuary (with a combined area of 2.4 km²) were interpreted. The first area was near Skeffling (E,N 533,419), a 1 km² section of marsh characterised by upper marsh, mid-low marsh, *Spartina* and pioneer marsh. The second area near Broomfleet Island (E,N 491,427), was a 1.4 km² section of marsh mainly characterised by upper marsh, reed beds and low-mid marsh.

Without ground data, there was no way of determining the accuracy of the classification using the two methods. However, a comparison was made to determine the level of agreement between the two outputs.

Times taken to undertake the two methods were also recorded so that a comparison could be made for how long it would take to complete the task using the different methods. This time does not include the set up time, as this would be identical for both methods.

Table 4. Comparing the point and line digitization methods for classifying saltmarsh with respect to work required.

	Points	Digitization
Number of units to classify	23,804 points	363 polygons
Length of digitized boundaries (m)	N/A	93,683
Time taken to complete task (Hours)	7	11.5

The point classifying method was faster than the line digitizing method. In addition, it was observed to be more robust. There were several times when working on the line digitizing method that the ArcGIS tools failed to function properly. Occasionally artefacts would appear in the digitized data layer (Figure 8) due to the extreme complexity of the shapefile being worked on. It is not uncommon for the programme to crash completely when digitizing such complex shapefiles, so it is important to break any work down into small chunks and to save it regularly. This is not an efficient way of working and will slow the procedure down considerably.

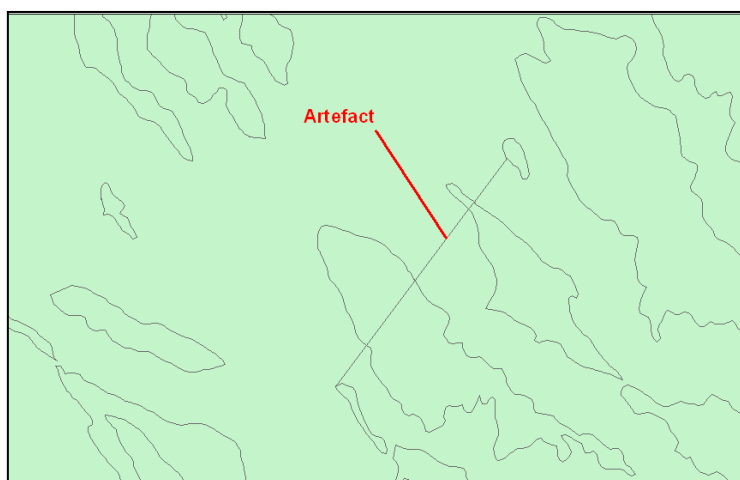


Figure 8. An artefact inadvertently introduced by bugs in the programme, during the digitizing process. This is a relatively common occurrence when manipulating extremely complicated shapefiles.

The point method does not have these problems because the only process that is taking place is to update the class field of an existing shape. If mistakes are made the class field can simply be updated with the correct class. The table is automatically saved with each class assignment. Many points can be selected using the range of selection tools (by rectangular box, by irregular polygon, or everything on the display screen) available within ArcMap.

6.4.1 Comparison of classification recording methods

The outputs from the two classification recording methods were compared by updating the point shapefile with the "class" field from the digitized polygon layer table using a spatial join. It is worth noting that the two classifications were carried out by the same interpreter. An example of how the two different classifications appear can be seen in Figure 9. The contrast of the visual appearance of the two methods is considerable. By its nature, the point method looks fragmented and the digitized classification looks more cohesive. This appearance can be misleading as the key factor is which method is most accurate and can be used for optimally monitoring change over time.

There are two key measures that can be extracted from the data to compare the level of agreement between the two methodologies. The first is the absolute overall number of points which were assigned to the same class using both methods. The outcome was that 91% of points were assigned to the same class using both methods. The problem with this statistic is that it tells you very little about the level of agreement of individual classes. This is because one class that is heavily represented in the saltmarsh, and which is possibly easier to discriminate by eye than other classes, would have disproportionate influence over this figure. It is therefore appropriate to normalise the data and produce a weighted overall percentage of agreement based on individual classes. However, as there is no independent reference against which to measure this statistic, it is necessary to perform this analysis twice: once assuming that the point classifier is 100% accurate and once assuming that the polygon digitisation method is 100% accurate. Thus, for each class, 2 percentages of agreement are calculated. There are 6 classes overall. So the mean of the 12 percentages of agreement can be reported as a weighted overall agreement percentage of 70%.

The statistics representing the level of agreement between the two different classification methods are presented in **Error! Reference source not found.** The mean percentage agreement figure is somewhat depressed due to two classes that have low representation (Pioneer, average of 12 points per method and Transitional Grassland, average of 78 points per method). This representation of the results highlights the difficulty in discriminating the classes that have low representation.

There are two main sources of disagreement. Firstly, the positioning of the boundary between different classes and secondly the actual class assignment. As the same person was responsible for the two different outputs, one might have expected a higher level of agreement among class assignment than that represented in **Error! Reference source not found.** This demonstrates that an interpreter can have a significant level of inconsistency when revisiting the same site. This would most likely be amplified with multiple interpreters.

Some example areas which compare the classifications from the two different methods are shown in Figures 9**Error! Reference source not found.** to 12.

Table 5. Percentage agreement for each of the classes, and a normalised weighted overall level of agreement, between the two methods of classification.

CLASS	Number of points in agreement	Point classification as a reference		Digitization classification as a reference	
		Points classified (area Ha)	Percentage in agreement	Points classified (area Ha)	Percentage in agreement
Pioneer	7	12 (0.12)	58.3	12 (0.12)	58.3
Spartina	1415	1573 (15.73)	90.0	1644 (15.73)	86.1
Mid Low	5805	6687 (66.87)	86.8	6453 (64.53)	90.0
Upper	10595	11223 (112.23)	94.4	11673 (116.73)	90.8
Reedbeds	3818	4153 (41.53)	91.9	4023 (40.23)	94.9
Transitional grassland	0	156 (1.56)	0.0	0 (0.0)	0.0
Total percentage of points commonly classified				Mean Percentage Agreement	
90.9%				70.1 %	

Much of the disagreement between the outputs of the two methods occurs close to boundaries between different classes. 64 % of all the disagreement is represented in a buffer region of within 10 metres distance from boundaries between the different classes. 89 % of all disagreement is within 30 metres of these boundaries (**Error! Reference source not found.**). This suggests that boundaries are extremely important to understanding the dynamics of disagreement between classifications.

It is worth noting that the differences in the class assignment are more likely to be due to interpretation inconsistency than due to the nature of the method employed. This comparison highlights one of the limitations of photography interpretation i.e. that an interpreter can be inconsistent with the interpretation if they repeat work in the same location.

The main disadvantage in using the point classification method is that areas where there are narrow strips of saltmarsh (which are thinner than the resolution of the point grid), may be missed in the analysis (e.g. in the Camel estuary).

Table 6. The spatial relationship of inconsistency between the two classification methods and distance away from class boundaries. The border disagreement figure is the number of mismatched points within each of the buffer zones expressed as a percentage of the total number of mismatched points across the entire study area. The majority of the disagreement is within the 10 metre buffer zone.

Buffer distance (m)	Border disagreement (%)	Accumulative border disagreement (%)
10	64	64
20	14	78
30	11	89
Remaining Points	11	100

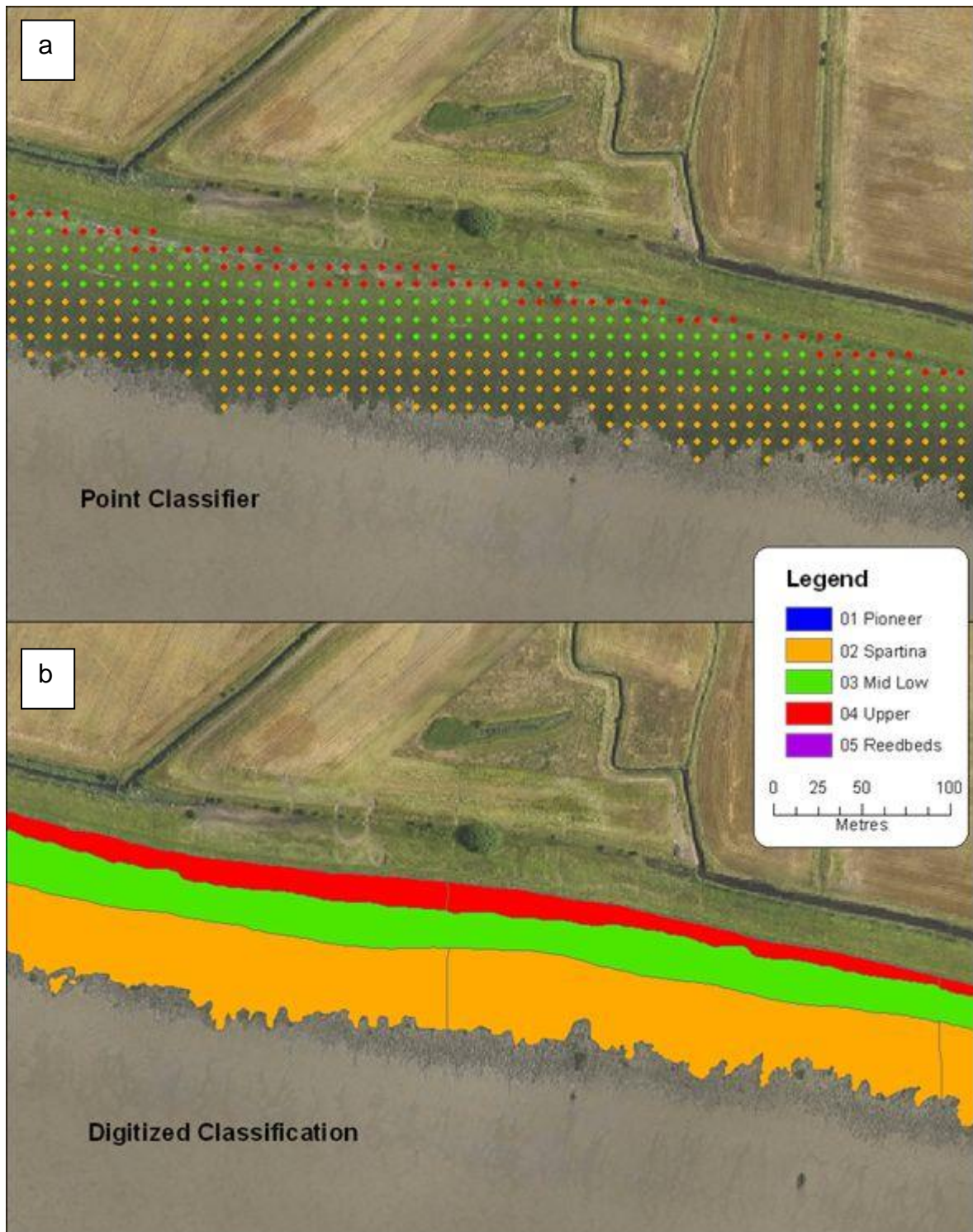


Figure 9. a) the point classification and b) the manual digitization. This section of saltmarsh is relatively simple in structure with a coherent transition between Spartina, mid low marsh through to upper marsh.



Figure 10. The point classification overlaid on top of the digitized classification. Areas where there is disagreement are characterized by the appearance of the points in the point classification. Areas of agreement between the point and digitized classification are shown up as a solid colour. In this image most of the disagreement is represented by inconsistent positioning of the boundaries.

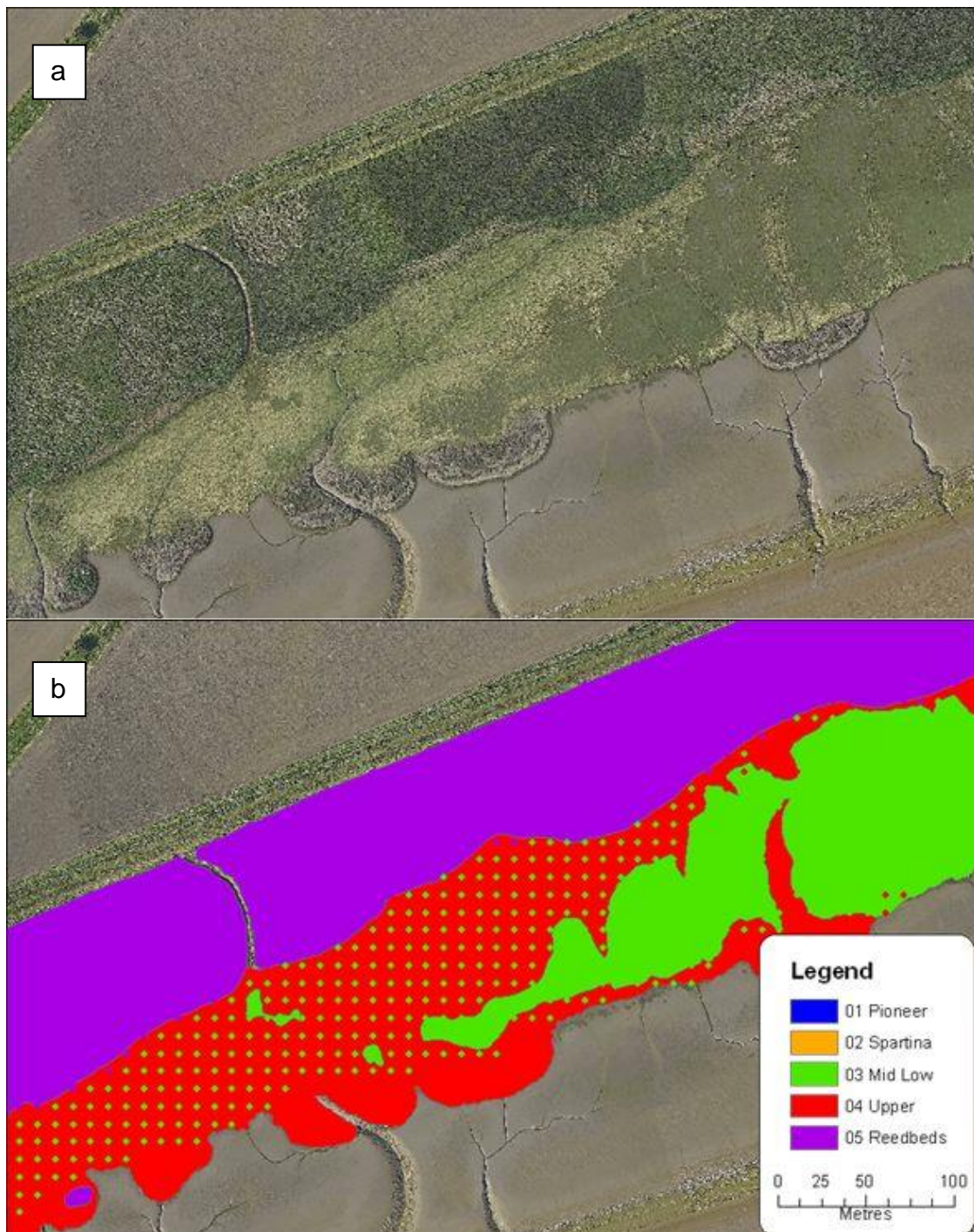


Figure 11. Broomfleet Island where digitizing and point based classification methods have been carried out. b) shows the classification with the point classified layer overlaid on top of the solid digitized polygon layer. Areas of disagreement between the two classifications are represented by coloured dots in the imagery. Solid colours with no dots signify agreement. The large area of green dots is an example of disagreement caused by inconsistent class assignment. It is likely an area of mixed *Agrostis* and *Festuca rubra* which could be assigned to either Mid-Low class or Upper class.

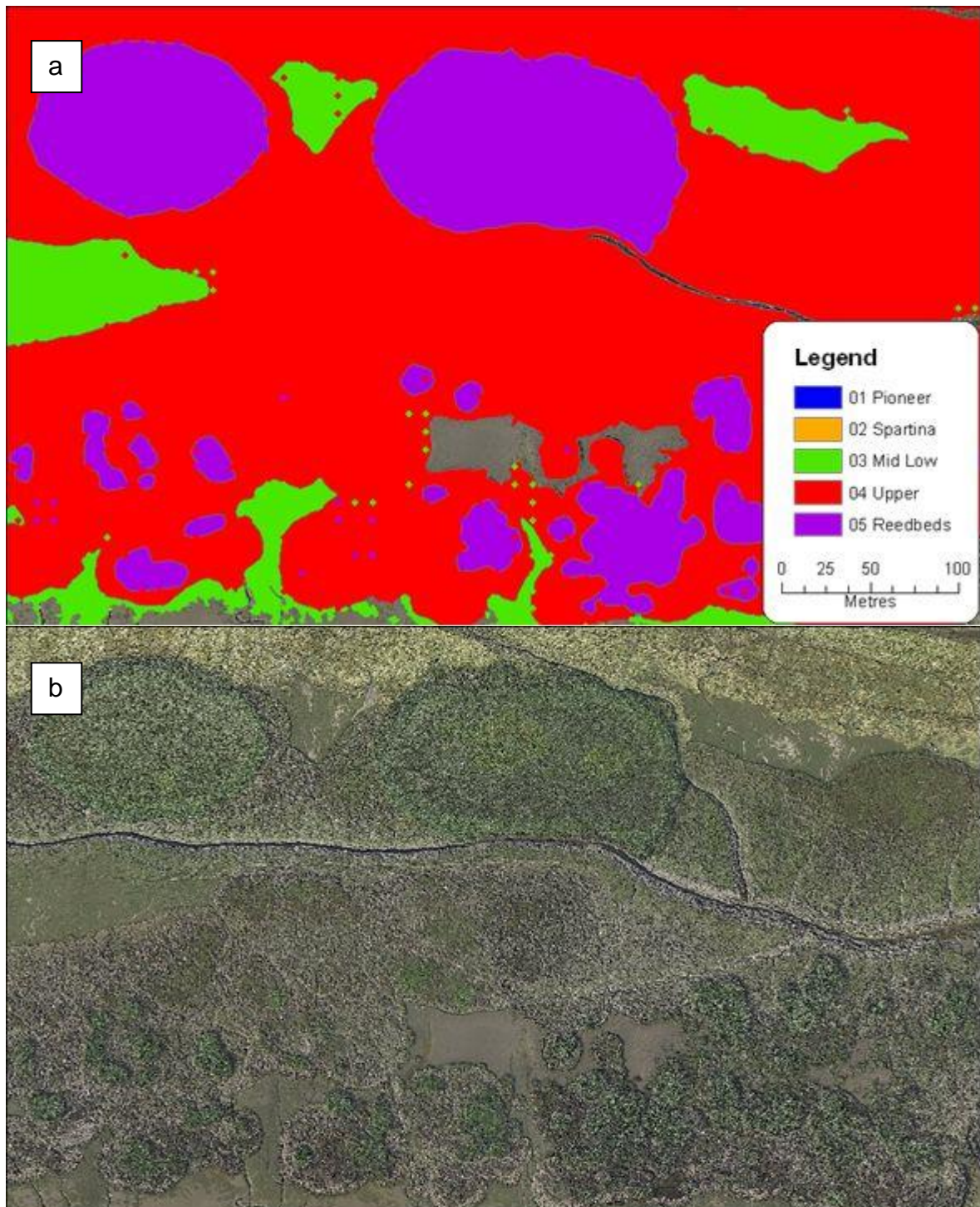


Figure 12. Saltmarsh near Broomfleet Island. Image a) zone assignment is more consistent in terms of class assignment and boundary positioning than Figure 11. The areas of disagreement are represented by dots in the classification image. Image b) shows the underlying photography data.

6.5 Development work for uncertainty in photointerpretation.

To address the issue of uncertainty surrounding photo interpretation an alternative approach to the analysis was undertaken in a subset of photos from the Humber estuary. In this approach, known as 'soft' or 'fuzzy' mapping, points where there is low confidence in the classification may be assigned to more than one zone. Soft mapping allows mapping areas of uncertainty by assigning multiple classes potentially reducing errors when change detection is carried out. If multiple zones are assigned then interpreter uncertainties are incorporated in the map, while also illustrating the possibility of effects such as ecotones. This soft approach does have some disadvantages:

- It is more complicated to carry out than hard classification.
- It may take longer to carry out than hard classification.
- The data could be more difficult to understand and analyse for people more used to traditional mapping outputs.
- Multiple classes may be allocated in a high proportion of areas where there is only a single class present. This may be due to inexperience, or an interpreter rushing to "get the job done" as quickly as possible. In this case the resultant map would be much less use for change detection.

Mapping using a soft approach could greatly increase the interpretation time and complexity if practical issues are not properly considered. Care has to be taken that multiple classes are not used to provide an easy way of evading difficult decisions, for example by specifying a maximum percentage of points that are allocated to multiple classes. If large areas that belong to a single class are mapped as belonging to multiple classes, this will reduce the usefulness of the map and the sensitivity of future change analysis.

Assuming that the point method adopted above was used, multiple classes could be allocated to points in uncertain areas or in ecotones (see Figure 13). If required, this approach could be used to generate the most likely class. For future change detection points where the classes allocated are completely different would have a high certainty of change. Points where some, but not all, of the classes were different would have a low certainty of change (Figure 13.d). These areas may be a focus for potential field surveys in following years.

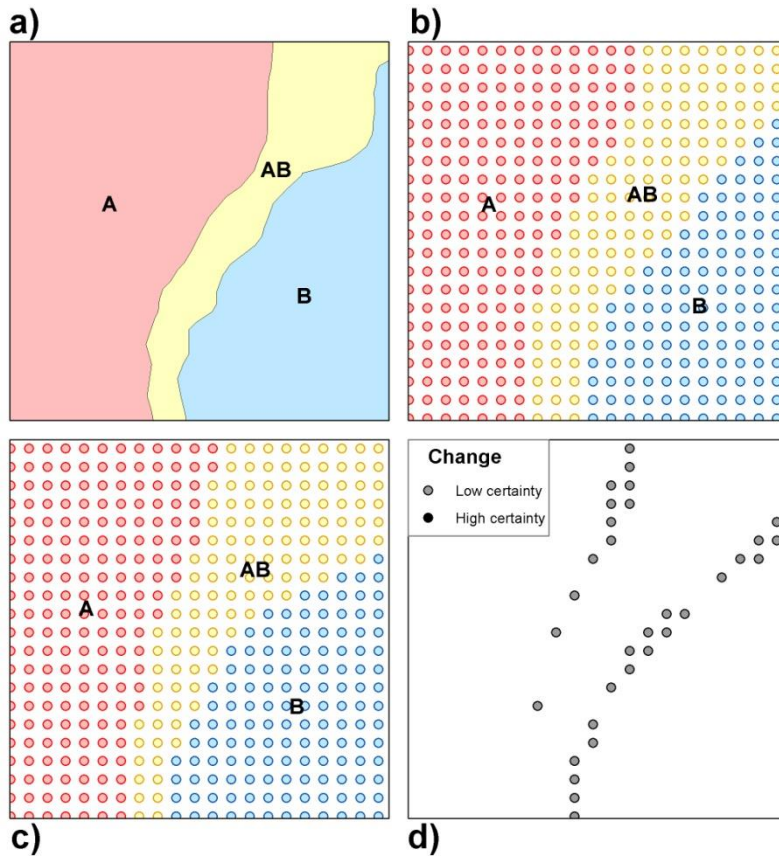


Figure 13. Soft point interpretations of the same reality. a) Actual ground classes A and B, with ecotone between them (yellow). b) One photo-interpreter's map with ecotone. c) Other interpreter's map output with ecotone. d) Areas of difference between interpretations. All the points of predicted change are assumed to be uncertain (grey points).

Comparisons were made between the two interpretations using all possible combinations of the alternative classifications to detect matches. In this preliminary test it was possible to reduce differences in interpretation from 13.5% to 3.3%. This is a large reduction in error, which has the potential to greatly reduce errors when change analysis is applied in the future.

Table 7. Different levels of agreement according to different matching criteria when introducing an alternative class in areas of least certainty.

Levels of agreement	Logical statement of agreement	Percentage of points consistently classified
1	Matches where: Interpreter 1 first choice = Interpreter 2 first choice	86.5%
2	Matches where: Interpreter 1 first choice = Interpreter 2 first choice OR	96.4%
	Matches where: Interpreter 1 first choice = Interpreter 2 second choice OR	
	Matches where: Interpreter 1 second choice = Interpreter 2 first choice	
3	Matches where: Interpreter 1 first choice = Interpreter 2 first choice OR	96.7%
	Matches where: Interpreter 1 first choice = Interpreter 2 second choice OR	
	Matches where: Interpreter 1 second choice = Interpreter 2 first choice OR	
	Matches where: Interpreter 1 second choice = Interpreter 2 second choice	

Further work is needed to understand the impacts of the work, both in terms of mapping saltmarsh and mapping saltmarsh change. Issues that should be examined include:

- The maximum number of alternative classes. In this brief study only two classes were considered, but there is potential to have more. However, the maximum number of classes for a single point will have impacts on accuracy, sensitivity of analysis and time taken.
- How would the work be carried out? Would the current tools be adequate or appropriate for this soft approach to interpretation?
- What are the impacts on time of interpretation? This is likely to be a function of the complexity of the area, the interpreter's experience and the number of classes allowed at a single point.

This is an approach that could be used in the roll out to provide the end user with more information about the limitations of aerial photography interpretation. It would clearly take more time to complete the mapping exercise than providing just a hard classification, but it is important that the data are used appropriately and understood by the end user, rather than regarding the interpreted work as an absolute truth.

An alternative approach of providing a measure of uncertainty, which would probably be even more robust, is to have multiple interpreters, allowing the interpretation to be repeated once or twice (although this may be impractical due to economic and time constraints). However, every area would be assigned a class multiple times. In points where there is a match in all of the

interpretations, there would be high confidence in the output data, and in areas where there was no match there would be least confidence in the output. These areas could be flagged up and treated with caution when analysing the data further.

6.6 Ground data for Zonation work in England and Wales

A database is being built up of transect and transition samples on saltmarshes throughout England and Wales. The transect and transition data are acquired on a 6 year cycle. These are used to inform interpretation based upon dominant species represented by the taxa information. Points that have not been used to inform the interpretation may be used in post-classification validation. This information is also used to inform species diversity in a reduced list.

In England and Wales for WFD, the ground truth methodology consists of transects walked from landward to seaward limit. For the transition data a waypoint is recorded where the saltmarsh vegetation changes from one zone to another. Information about the change “from and to” is also recorded. In the centre of each zone, several quadrats are laid down. Within each of these, all species present are recorded along with their percentage cover.

Transects must:

- a) be placed primarily to address health and safety issues such as avoiding large creeks and gullies.
- b) cover the saltmarsh from the landward to seaward extent. During the field survey you can work in either direction: seaward-landward or landward-seaward.
- c) be placed to cross over the areas of the marsh which encompass the most communities. In some, but not all cases this will be perpendicular to the coastline,(see Figure 1). It is acceptable to produce transects which zigzag across the marsh. Transects are positioned approximately every 500 metres to 1 kilometre along the saltmarsh.

Part of the ground data acquisition is driven by some of the uncertainty observed in the previous classification. Requests for ground visits are made in those areas that are assigned an alternative class. When new data are collected, the classification may be revisited to update it reflecting the new information made available. If changes need to be made to the classification based on new information made available then it is necessary to scan through the original classification and image data for that water body to see if other areas need to be updated accordingly.

This ground database can be used to enhance and validate the existing zonation maps and to inform future classifications as new aerial photography data becomes available.

Saltmarshes should be visited, especially in those areas where an alternative class has been used in order to validate the classification. Once the map has been completed, if and when new information becomes available that

invalidates the classification, modifications should be made to the original to reflect this new information. An advantage of the point classification method is that it is quite straight forward to modify the attributes of the shapefile in the point dataset.

Errors are more critical in the extremes of vegetation, for instance in the pioneer and transitional zones as this can also affect the extent map. These zones should, if possible, be the focus of the greatest volumes of requested ground data.

6.7 Zonation aggregation of communities

The EA classification system has been tailored to

- a) Provide one tier down from an extent map to track high level community changes.
- b) Align better with what can be consistently photointerpreted from aerial photography.

The system matches well with the NVC Classification but there are some adaptations. The main change is to call 'high marsh species' with *Puccinellia*, 'Mid marsh' – because that's how they will generally appear from the air. This modification provides more consistency but it is accepted that it will not be perfect. The IHS column should only be seen as a rough comparison with greater confidence in the NVC classification alignment.

Table 8. Different levels of agreement according to different matching criteria when introducing an alternative class in areas of least certainty.

Zones	Principal species	Other species	NVC	IHS
Pioneer	<i>Salicornia</i>	<i>Suaeda</i> , <i>Puccinellia</i> , <i>Halimione</i> , <i>Limonium</i> , <i>Aster</i> , <i>Arthrocnemum</i>	SM7, SM8, SM9	LS311 LS312 LS313 LS31Z
Spartina	<i>Spartina</i>	<i>Algae</i> , <i>Puccinellia</i>	SM4, SM5, SM6	LS321 LS32Z
Mid-low marsh				
- low	<i>Puccinellia</i>	<i>Salicornia</i> , <i>Suaeda</i> , <i>Aster</i> , <i>Spartina</i>	SM10, SM11, SM12, SM13	LS331 LS332
- mid mid	<i>Halimione</i>	<i>Puccinellia</i> , <i>Juncus maritimus</i> , <i>Suaeda</i> , <i>Triglochin</i> , <i>Plantago</i> , <i>Glaux</i>	SM14, SM15	LS333 LS3363
- upper mid	<i>Festuca</i>	<i>Plantago</i> , <i>Triglochin</i> , <i>Juncus gerardii</i> , <i>Agrostis</i> , <i>Glaux</i> , <i>Armeria</i> , <i>Limonium</i> , <i>Artemisia</i> , <i>Halimione</i> , <i>Puccinellia</i> , <i>Juncus maritimus</i> , <i>Suaeda vera</i> , <i>Frankenia</i> , <i>Spergularia</i> , <i>Salicornia</i>	SM16, SM17, SM21, SM22, SM23	LS3361
High marsh	<i>Elytrigia</i> , <i>Agrostis</i> without <i>Puccinellia</i> , <i>Festuca</i> without <i>Puccinellia</i> , <i>Juncus maritimus</i> without <i>Puccinellia</i> , <i>Bolboschoenus</i>	<i>Juncus gerardii</i> , <i>Triglochin</i> , <i>Plantago</i> , <i>Oenanthe</i> , <i>Trifolium</i> , <i>Glaux</i> , <i>Blysmus</i> , <i>Inula</i> , <i>Atriplex prostrata</i> , <i>Halimione</i> , <i>Suaeda vera</i> , <i>Elymus repens</i> , <i>Potentilla</i> , very small amounts of <i>Puccinellia</i>	SM18, SM19, SM20, SM24, SM25, SM26, SM27, SM28, S21	LS3362 LS37 EM13
Phragmites	<i>Phragmites</i>	<i>Zostera noltii</i> at low levels; <i>Atriplex prostrata</i> ; <i>Puccinellia</i> (V) in S4dii	S4d	EM11

6.8 Glossary

Colour balancing	The process of rendering exposures so that the lighting levels match those of adjacent exposures thereby enabling a seamless mosaic of photographs to be generated
Contrast stretch	Contrast stretching attempts to improve an image by stretching the range of intensity values contained in its pixels to make full use of possible values.
Differential GPS	Differential Global Positioning System (DGPS) is an enhancement to Global Positioning System that provides improved location accuracy, from the 15-meter nominal GPS accuracy to about 10 cm in case of the best implementations.
Digital aerial photography	Aerial photography is the taking of photographs of the ground from an elevated position. In the context of mapping these are usually captured using digital cameras pointing directly downwards towards the Earth's surface to minimise geometric distortions in the image data and more easily enable the data to be registered to a map co-ordinate system.
Ecotone	An ecotone is a transition area between two biomes. It is where two communities meet and integrate
Extent mapping	Process of delineating the boundary of a single land cover type such as saltmarsh
Full colour	Imagery comprising three image-bands (Red, Green and Blue) to approximate what would be seen by the human eye in real life
GIS	A geographic information system (GIS) is a computer system designed to capture, store, manipulate, analyze, manage, and present all types of geographical data.
Good Ecological Status	defined in Annex V of the Water Framework Proposal, in terms of the quality of the biological community, the hydrological characteristics and the chemical characteristics
Ground data	Information collected from the locations within the study area of known land cover type and of verifiable quality which can be used to inform the image classification process or to assess the accuracy of the output.
Ground Sample Distance	In remote sensing, Ground Sample Distance (GSD) in a digital photo (such as an orthophoto)

	of the ground from air or space is the distance between pixel centers measured on the ground. For example, in an image with a one-meter GSD, adjacent pixels image locations are 1 meter apart on the ground.[1] GSD is a measure of one limitation to image resolution, that is, the limitation due to sampling
Image classification	The assigning a thematic class to the pixels of a complex image data set such as aerial photography or satellite imagery into a simplified through automated or semi-automated means.
Integrated Habitat System	The Integrated Habitat System (IHS ©) Somerset Environmental Records Centre. A plant community classification system that integrates UK BAP priority habitat and Habitats Directive Annex 1 classes within a hierarchical structure
Manual digitisation	Process of delineating the boundary of a land cover type using visual interpretation and on-screen vector layer generation
Minimum creek width	The smallest width that a creek will be mapped
National Vegetation Classification	The National Vegetation Classification (NVC) is one of the key common standards developed for the country nature conservation agencies. The original project aimed to produce a comprehensive classification and description of the plant communities of Britain, each systematically named and arranged and with standardised descriptions for each.
Near-Infrared	Infrared (IR) light is electromagnetic radiation with longer wavelengths than those of visible light, extending from the nominal red edge of the visible spectrum at 700 nanometers (nm) to 1.4 µm. Particularly important for vegetation mapping and generation of vegetation index image layers
Photographic interpretation	The process of examining photography data in order to identify and record features within it.
Root Mean Square Error	The Root Mean Square Error (RMSE) (also called the root mean square deviation, RMSD) is a frequently used measure of the difference between values predicted by a model and the values actually observed from the environment that is being modelled
Semi- automated digitisation	Combination of automated and manual image feature extraction techniques
Zonation mapping	The process of identifying and recording different vegetation communities in aerial photography in a spatial context.

