



Universiteit Utrecht

# Spatial and temporal development of riparian vegetation objects



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Master Thesis

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## **Abstract**

The use of dynamic vegetation modules in geomorphodynamical modelling provides more natural looking river and vegetation patterns. However, a way to validate these model results is not available. This means that there is a need to study the development of riparian vegetation and its patterns. In order to study riparian vegetation development over a longer time period, historical aerial photography is used. This study developed a method to extract isolated vegetation objects from historical grayscale aerial photography. Land cover and isolated vegetation objects were classified using object based image analysis. In a GIS environment the spatial and temporal development of the objects was analyzed. Spatial patterns of objects were analyzed by plotting these objects on maps along with characteristics as relative age, area and shape. The analysis of objects indicated dynamic vegetation development with new and disappearing objects. Spatial patterns in area and shape of objects were not present, though patterns in objects themselves were visible. The results of this study are a first step in obtaining data to validate model results.

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# 1 Introduction

Vegetation patterns in river systems were long seen as the result of the river morphodynamics. Thus research on the riparian vegetation was often approached from the morphodynamic side, i.e. the effect of river morphodynamics on the vegetation (Bendix and Stella, 2013). These studies try to predict vegetation distribution and succession based on morphodynamic parameters (Camporeale and Ridolfi, 2010; Rivaes et al., 2014;). The reverse effect of the riparian vegetation on the river morphodynamics, however, is less studied (Bendix and Stella, 2013). Current understanding is that strong feedbacks between vegetation and river processes control the resulting landforms and patterns (Corenblit et al., 2011; Gurnell et al., 2014).

The relation between vegetation and river is studied with both scale experiments and models. Perucca et al. (2007) shows the influence of vegetation on meander migration by coupling morphodynamic processes with vegetation processes. Using scale experiments Van Dijk et al. (2013), researched bank erosion and floodplain development. They observed strong influence of vegetation on bank erosion and resulting river patterns. Recent developments in morphodynamic models update static vegetation to a dynamic vegetation module. Van Oorschot et al. (2015) for example, modelled river development by coupling a geomorphodynamical model with a dynamic vegetation model. Results of this study show more natural river development and emerging vegetation patterns.

However, a means to validate these model results with real life situations is lacking. This is a result of the problem that hardly any research is done on the development and patterns of riparian vegetation itself. Even though, information on the development and patterns of riparian vegetation is needed to improve the interpretation and model results. Available research deals mostly with observing development and do not provide quantification on vegetation itself. Geerling et al. (2006) studied the succession of different riparian ecotopes at the river Allier and provided a general succession scheme (figure 1.1). They showed that succession there showed two main paths, succession from bare soil and succession from a closed side channel. This results into either grassland vegetation or forest respectively, two very different end results. The paper provides important information on the succession on the different types vegetation, though it lacks information on the actual vegetation.

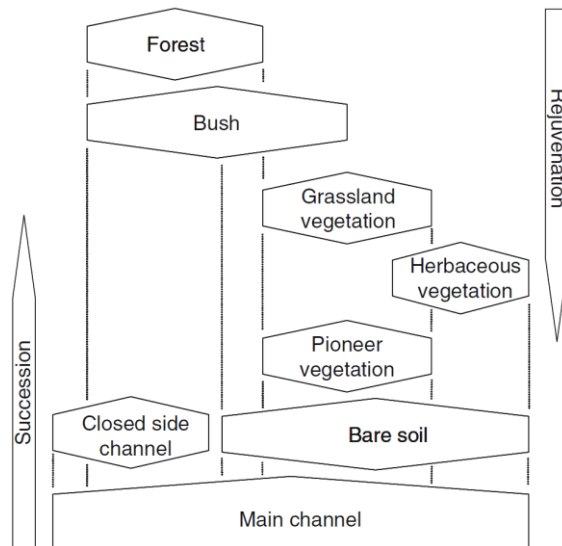


Figure 1.1: Succession scheme of the ecotopes along the river Allier (Geerling et al., 2006)

The goal of this research is to determine spatial patterns and temporal development of isolated vegetation objects in riparian vegetation. To research temporal development, a data set spanning a larger time period is required. Such a data set can be acquired from historical aerial photography. This photography is most often grayscale, though the resolution is high enough to distinguish different vegetation cover and types (Geerling et al. 2006). The goal is to study the development of isolated vegetated objects as single trees and shrubs usually come first during succession from pioneer to climax. These objects are thus interesting to follow as they develop.

To achieve this goal, a few questions are stated:

- 1) How can isolated objects be extracted from historical aerial photography?
- 2) How do isolated objects develop over time?
  - Class, size, shape
- 3) What are the spatial patterns of objects?
  - Surviving objects, Disappearing objects
- 4) What are the characteristics of the different groups of objects?
  - Size, shape, position

Available data on vegetation is in form of grayscale aerial photography. The lack of spectral information limits the interpretability of surface features. This leads to the first question on how isolated vegetation objects can be extracted from this photography. Since there is no method available to extract these objects, a new one will be developed. When the required objects are extracted, it leads us to the development of these objects. Development of objects over time in terms of: change in class (background vegetation), change in size. Knowing the development of objects, the next step is to see where these

developments occur. Where do new objects appear, where do objects survive and where do they disappear? This can be elaborated by examining the characteristics as shape, size of these groups of objects, are there any spatial patterns related to shape and size?



## **2 Methods**

### **2.1 Method overview**

A method had to be devised to go from printed aerial photographs to information on vegetation. This section will provide an overview for the method used to extract vegetation polygons from aerial photography. To analyse the photography using software they were digitized. To facilitate comparing images and to make sure the surface pixels were corrected for height differences the images had to be orthorectified. This ensures that all images are in the same coordinate system and surface is comparable. Having orthorectified images also facilitates working in a GIS environment as the images can be plotted on top of each other.

With orthorectified images of the photography we can move on to the next step which is extracting the information from the images. For this research it was chosen to classify the imagery of the study area by using object based image analysis (OBIA) (eCognition, Trimble 2015). The main reason for this choice was that the images are grayscale. This means that due to lack of spectral information, classification is mainly based on shape and context. Secondly, an interest in vegetation objects made classification based on objects much more attractive as objects of interest can be extracted during the classification. Using OBIA the images were classified and isolated vegetation objects were extracted. For further analysis in GIS, a shape file with isolated objects and the surface classification for each image was exported from eCognition. In these shape files isolated objects retained their coordinates and information on class, size and shape.

In this part of the analysis information on the development of the isolated objects is obtained. Shape files are intersected with each other in ArcMap (ESRI ArcGIS, 2015). Intersects of shape files provide new objects with attributes from its intersecting shape files. The lists of objects obtained from these shape files contain the development of isolated objects. These lists are adjusted and supplied with codes which describe change in class, in order to be plot in maps.

The above overview of the methods provides in short how one goes from printed aerial photography to information on development of vegetation. In the following sections orthorectification, classification and analysis of isolated objects are explained in more detail.

## 2.2 Study area

To study change in riparian vegetation a location with active river morphology which is not laterally confined is preferred. On top of that, availability of a data set which enables one to study the changes is needed as well. One of the few rivers in Europe which has parts where the river can still meander freely is the Allier in central France. The French geographical institute (IGN) has a database of historical aerial photographs with which observing the changes and development of the riparian vegetation is possible.



Figure 2.1: Location of the study area. The subset used in the research is lined with green.

The study area is a stretch of river south of Moulins and north of Chatel-de-Neuvre. The Allier is a tributary to the river Loire. It is a rain-fed river with a mean annual discharge of  $140 \text{ m}^3/\text{s}$  and a mean peak discharge of  $500 \text{ m}^3/\text{s}$  (Crosato and Saleh, 2011; Van Dijk et al., 2014). The river features active growth of point bars, bank erosion and frequent chute cut-offs (Kleinhans and Van den Berg, 2011). The dynamic surface conditions make studying both vegetation development and river morphodynamics interesting in this area. This stretch of river was chosen as it features the highly dynamic meandering. This active meandering provides areas where succession from bare soil, to pioneer and climax vegetation can be present. Riparian vegetation along the Allier consists of: forest, bush, grassland and herbaceous vegetation (Van den Berg & Balyuk, 2004).

For this study area aerial photography is available every two to ten years starting from 1946. In this research photographs from three years are used: 1968, 1975 and 1980. All three images are grayscale with different scales. The resulting pixel sizes are thus also different from one image to another.

*Table 2.1: Aerial photography used in this research and their characteristics.*

Year	Colour	Scale	Pixel size after processing (cm)
1968	Grayscale	1:25000	26
1975	Grayscale	1:16000	19
1980	Grayscale	1:30000	33

## 2.3 Orthorectification

In this section the methods regarding orthorectification are explained. This process entails positioning of the images in a geographical reference system and removing distortions caused by elevation differences by resampling the images. Required information for orthorectification of aerial photography are: information about the photography and camera, ground control points and a digital elevation model (DEM). Information about the photography and camera, like fiducials and focal length, are needed to know what is projected in the photography. This determines the internal orientation. The external orientation is determined by using ground control points. These points make sure the photography is positioned correctly in the geographical reference coordinate system. When the external orientation is complete orthorectification can be applied. During this process a DEM is used to correct the distortions due to elevation differences. When there is no high resolution DEM available it can be made by using photogrammetry from two or more images to create an elevation model. The result of the orthorectification is an image with a known pixel size and projected within a coordinate system. This facilitates comparing with other imagery of the same area from different years in a GIS environment. In the following sections the steps of orthorectification will be explained in further detail.

### 2.3.1 Acquiring photography and camera information

Photography is obtained from "institute national de l'information géographique et forestière" (IGN). The first step in orthorectification requires information about the photography and camera. This consists of fiducials, focal length and average flying height. Fiducials are the markers which are found on the edges of the photography. They are needed to determine the internal orientation which will be explained in the next section. From the fiducials the distance between them is required. The name and focal length of the camera is often mentioned on the information strip on the photography (figure 2.2). If the flight height or focal length is not mentioned on the photography or provided by the publisher it can be calculated if at least two of the three components (scale, flight height and focal length) are known (equation 1).

*Equation 1:*

$$Scale = \frac{Flight\ height\ (m)}{Focal\ length\ (m)}$$

In addition to the photo and camera characteristics, a reference coordinate system is required. This determines in which geographical coordinate system the photography will be projected. When all the necessary information is collected they can be put into the software.

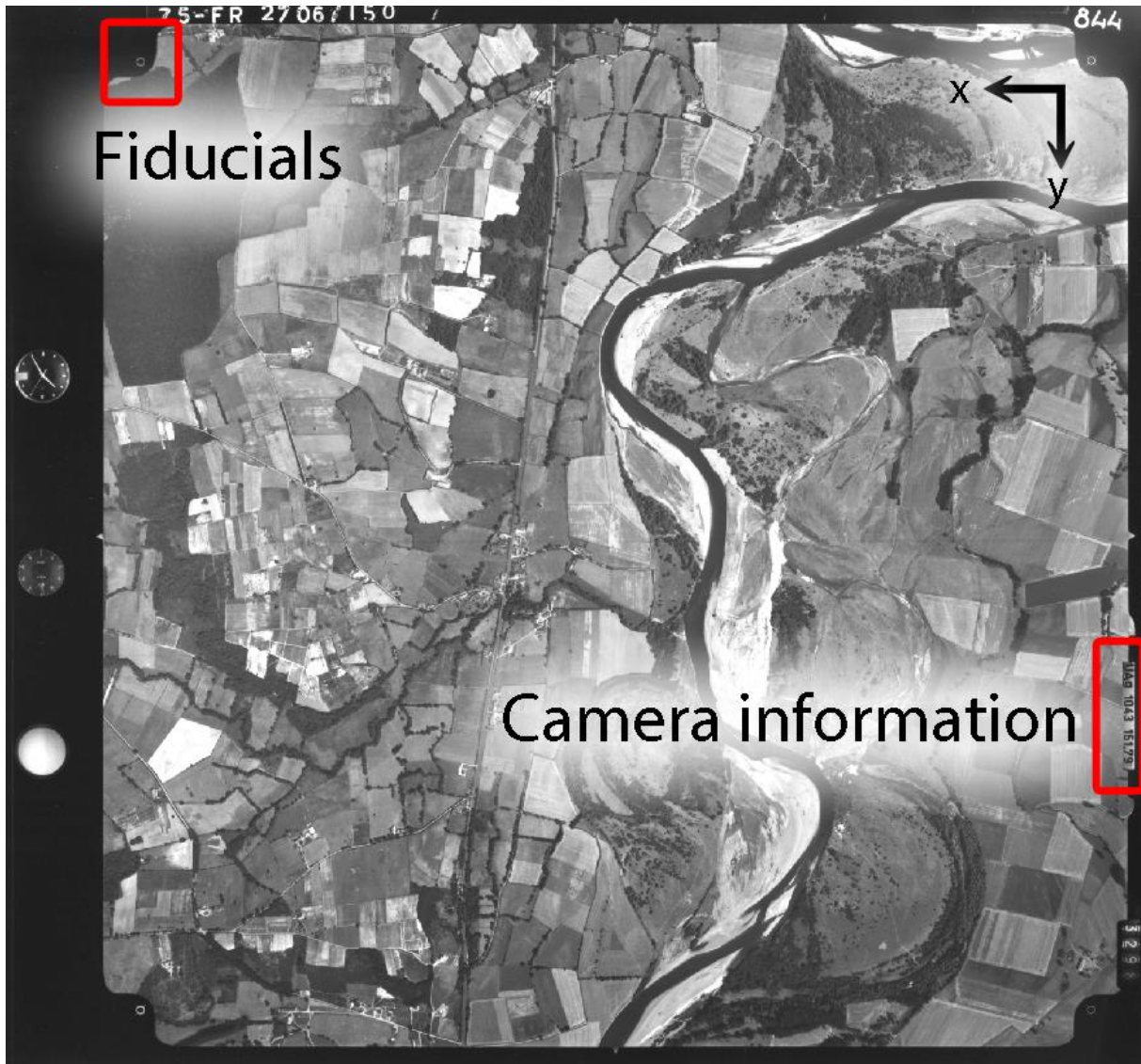
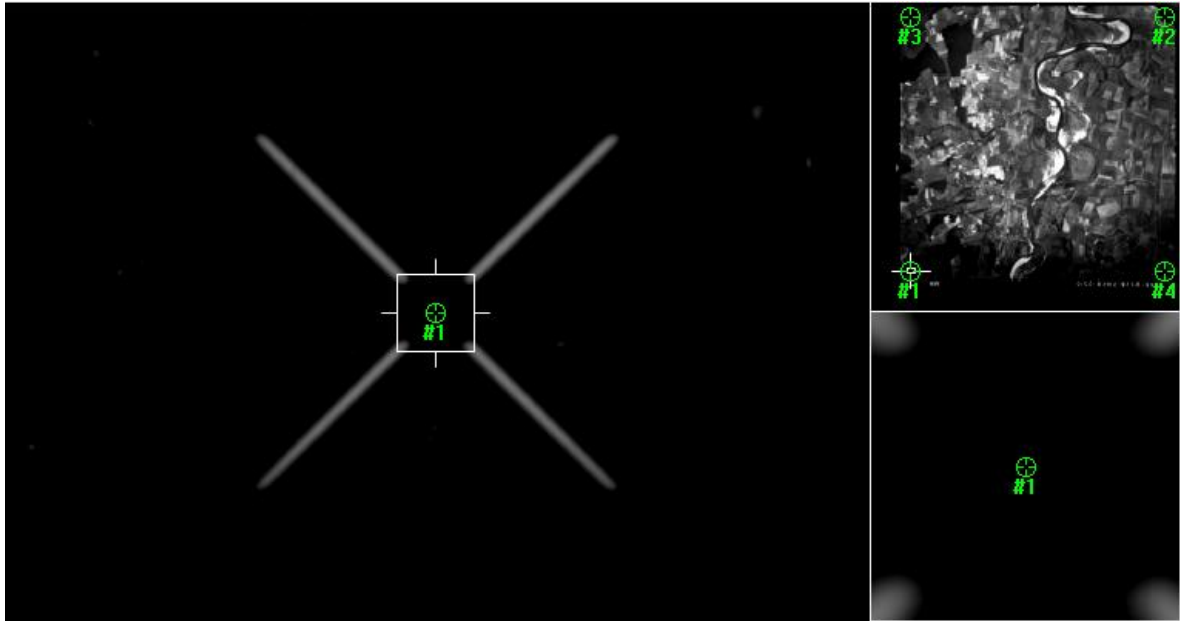


Figure 2.2: Information present on an Aerial photograph. Fiducials and information on the camera are highlighted on this image. In the top right is indicated how the x- and y-axis are aligned.

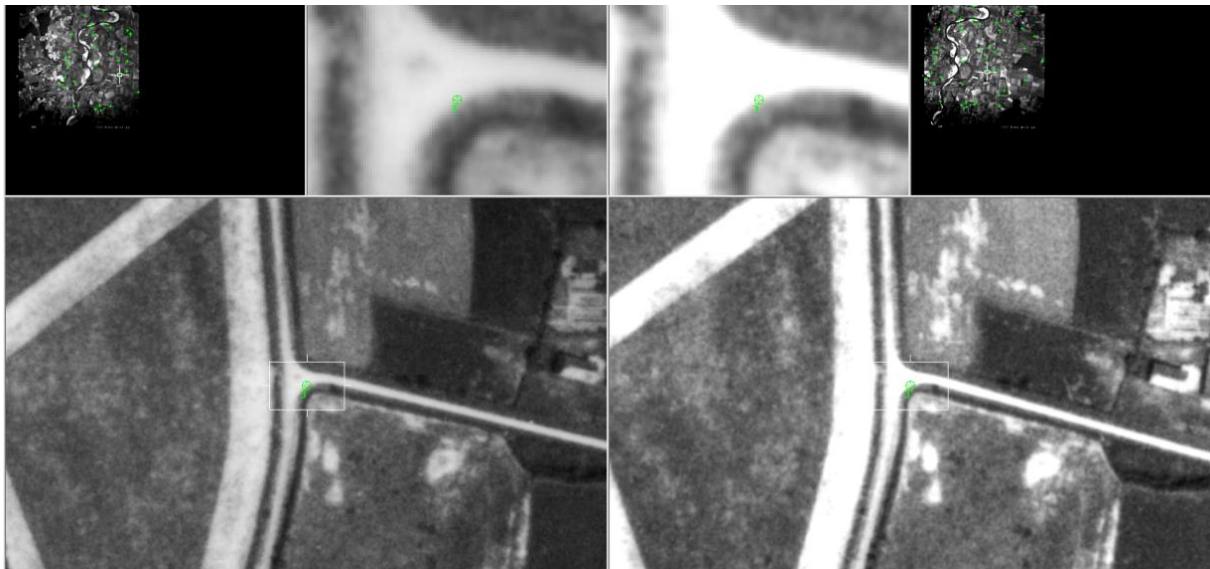
### 2.3.2 Image orientation

To determine the internal orientation the fiducials and the camera characteristics are used. The distance between the fiducials was measured earlier for the camera characteristics. In this step the software is told where the fiducials are located on the photography (figure 2.3). The axis configuration is chosen in such a way that the y-axis is always along the information strip on the image. This information strip is often the side at which the camera information is printed. After the configuration of the fiducials the images have an internal orientation. Now we can move on to the external orientation.



*Figure 2.3: Locating the fiducials on the photography.*

For the external orientation, ground control points (gcp) will be allocated in the imagery (figure 2.4). It is preferred that these points can be located on both images and can be recognized after many years so reference coordinates from Google Earth or GPS can be found. Examples of such points are road intersections and edges of building. In this research the coordinates are obtained from Google Earth and elevation values are taken from the IGN top-maps where possible. After allocating the gcp's the program calculates tie points. These tie points are used in addition to the gcp's to tie the images together.



*Figure 2.4: Setting up the ground control points.*

The software asks for at least six tie points or three ground control points in order to perform the triangulation. The triangulation summary reports the RMSE which is an indication of the overall pixel error between the images for each gcp and tie point. When determining the exterior orientation we strive for a RMSE as low as possible. When a satisfying triangulation is obtained it is accepted and now coordinates are added to the images.

### **2.3.3 Creating the point cloud and DEM**

When the images have an exterior orientation and a DEM is available the images are ready for orthorectification. However for this research a high resolution DEM was not available. When a DEM is not available it can be created if there are two or more overlapping photos available. The photogrammetry software will calculate a point cloud of the terrain surface in the overlapping parts of the images. From this point cloud a DEM is created. The quality of the DEM depends on the amount of points in the point cloud and the scale of the photography. Photography with little noise, smaller scale or having three or more overlapping images will most likely increase detail in the point cloud and thus detail in the resulting DEM.

### **2.3.4 Ortho-resampling**

During orthorectification, the images are resampled according to the DEM. This removes the distortions in the image due to elevation differences. Surfaces with trees or water are not handled well in elevation extraction and often cause distortions during resampling (Figure 2.5). After resampling the pixel sizes are known and the image is projected in a coordinate system. It results in an image that can be used in GIS environments. It also facilitates comparing images of the same area from for example different time periods.



*Figure 2.5: Distortions in trees caused by resampling are seen in the dark bend of trees indicated with a red arrow*



## 2.4 Classification

The images are classified to simplify the information it contains and produce products which can be used in further analysis. Since most photography of the study area is grayscale it is hard to use an automatic or supervised pixel based classification as there is a lack of spectral information. This means that without context a gray water pixel is not distinguishable from a gray vegetation pixel. Because of this, object based image analysis (OBIA) is applied using the software eCognition (Trimble, 2015). OBIA makes use of segmenting algorithms to divide the image into a mosaic of objects. This enables the user to use shape, texture and contextual features for a more accurate classification.

As the imagery differs in pixel sizes and brightness values, different parameters for segmentation and classification are used for each image (table 2.1). Segmenting is done by using scale 30 or 50 with shape and compactness of 0.1 and 0.5 respectively. This results into objects with an average size of 180 m<sup>2</sup>.

Table 2.2: Parameters and details of the imagery

Parameters and details of the imagery				
year		1968	1975	1980
Pixel size (m)		0.26	0.19	0.33
Segmentation scale		30	50	30
Segmentation param.	Shape, compactness	0.1, 0,5	0.1, 0.5	0.1, 0.5
Object fusion variables	max_texture_difference	1	1.5	1.5
	min_common_border	0.2	0.05	0.05
	min_spectral_difference	15	10	10
Brightness Thresholds	Bright - Low	200	180	210
	Low - High	93	80	100
Isolated object thresholds	Objects from low vegetation and bare soil (area in m2)	<50	<50	<50
	Shape index	<2	<2	<2
	threshold small/large (area in m2)	<30	<30	<30

With classified images we have a representation of the surface cover in the study area. The surface is divided into: Low Vegetation, High Vegetation, Bare soil, Main channel and Channel remains. From the Low Vegetation and Bright classes isolated objects are extracted. Of these isolated objects shapefiles are exported with information on their area, shape index and class. The classification of the other surfaces classes will also be exported as a shapefile. These shapefiles will then be used to analyze the changes of these isolated objects. The analysis of these shapefiles will be discussed in the next chapter.

**2.4.1 Workflow of classification**

The classification is done by using a semi-automatic approach. A rule-set is made to guide the classification, though some classes were classified manually. Parameters of algorithms change for each image due to differences in the image brightness and resolution (Table 2.2). The sequence in which the surface is classified is waterbodies, remaining land cover and isolated objects (Figure 2.6).

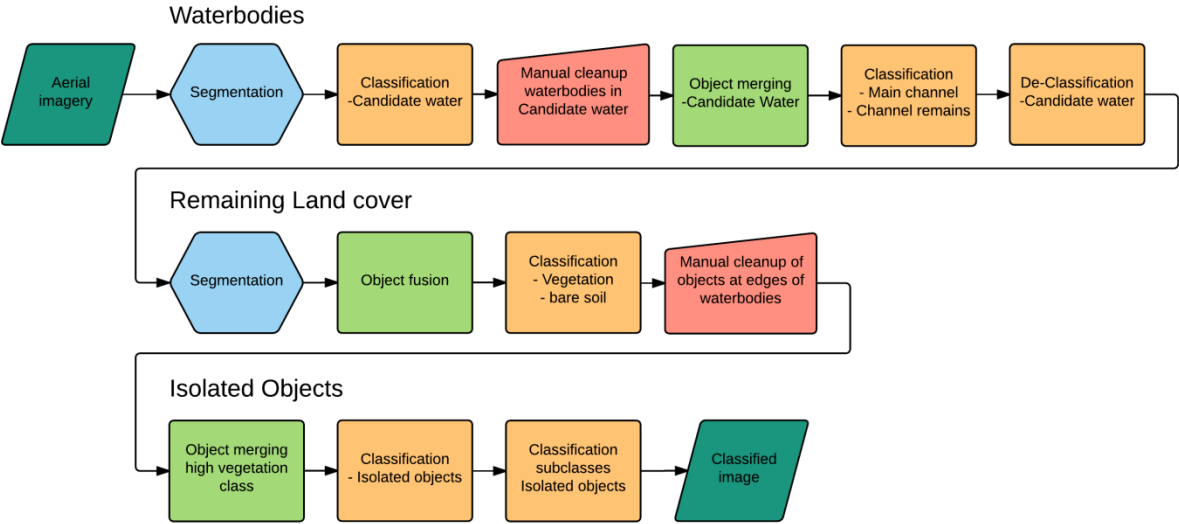


Figure 2.6: Workflow of classifying aerial imagery. The classification is a continuous process where the arrows indicate the sequence in the process. Colours indicate similar processes: Blue for segmentation, orange for classification, red for manual input and green for object merging.

First, waterbodies are classified to facilitate classification of the vegetation in which we are interested. The darker areas in the images are either vegetation or waterbodies. There is a small distinction based on brightness and texture between these two. However, this distinction is too small in order to create rulesets that accurately classify the image within the available time and waterbodies are not the focus of the study. Therefore the waterbodies, which includes the main channel and channel remains, are classified semi-automatically. This is done by automatically assigning dark objects

which are most likely part of a waterbody as a candidate for water class. This automatic indication will also add parts of dark vegetation and thus requires manual clean up until the main channel and channel remains are classified correctly.

The remaining land cover is then divided into three classes based on grayscale thresholds. These classes are low vegetation (gray), high vegetation (dark) and bare soil (bright). Thresholds for the divisions are determined visually. Due to the differences in brightness between the images these thresholds are varying (table 2.2). Dividing the vegetation based on the brightness may cause some discrepancies on the surface classification as brightness levels are not the same throughout the whole images for the same class. This was remedied as much as possible by carefully choosing thresholds.

Objects of interest for this research are isolated vegetation points. This entails trees, shrubs or other vegetation visible as a point on the surface. From the high vegetation class the isolated parts with a maximum size of 150 m<sup>2</sup> were merged as a single object in order to classify those parts as isolated objects. The other isolated objects are extracted from the low vegetation and bare soil surface classes. The main characteristic of an isolated object is that it is darker than its surroundings. This means that an object will be indicated as an isolated object when its surrounding objects are brighter. The main advantage of extracting them on this characteristic is that it works the same for both objects with bare background, and low vegetated background. To reduce false positives, objects were extracted as an isolated object when their shape index is lower than two and their size smaller than 50 m<sup>2</sup> (table 2.1). Increasing the size causes more false positives. Checking if isolated objects were classified correctly was done visually. The maximum sizes were found iteratively by checking the objects manually for different sizes. Isolated objects are divided into small and large objects. This results into four isolated object classes: small and large with a bare soil background, and small and large with low vegetated background. After classification these objects are exported in one shapefile with information on size, shape, and class.

Validation of the classifications is done visually. By using historical aerial photography it is not possible to obtain ground truth information, thus the accuracy of the classification cannot be checked.

## **2.5 Analysing isolated objects**

The analysis focusses on the development and spatial patterns of the isolated objects in the study area. The main questions the analysis will need to answer are: "How do the isolated objects develop?" and "What are the spatial patterns?" To analyze the development the objects are intersected in a GIS environment using ArcMap. This will result in information on the development of the objects. Development of the objects can be derived from change in class numbers between the different images. Determining spatial patterns requires the objects along with characteristics as shape or size to be plotted in a map. The process of analyzing the objects is explained in the following sections.

### **2.5.1 Analysing the development of objects**

The analysis starts with the shapefiles which are exported from eCognition. These shapefiles contain the shapes of the isolated objects and can be plotted on top of each other (Figure 2.7). The shapefiles contain information on the area, shape and class for each object. Overlapping areas of the objects will have information on attributes of the overlapping objects. Which can be extracted by intersecting the shapefiles in GIS.

The intersect tool in ArcMap creates a new shape file with shapes of the overlapping areas in the current intersecting shapefiles. New shapes have the attributes of all intersecting shapes in the intersecting shape files. This gives information on how the objects developed over time. Since not all objects overlap, intersects of multiple combinations have to be made (Table 2.3). Objects may occur in intersects from multiple combinations. To make sure each combination has a list of unique objects they are filtered based on the ID-numbers of overlapping years.

In these lists one can see which objects survive during the time step and which objects disappear. One thing that is not yet present in these lists is where the disappearing objects change into. To see the information on the objects which disappear, they are intersected with the classification of the following year. This results into an extra column with the class which replaces the object.

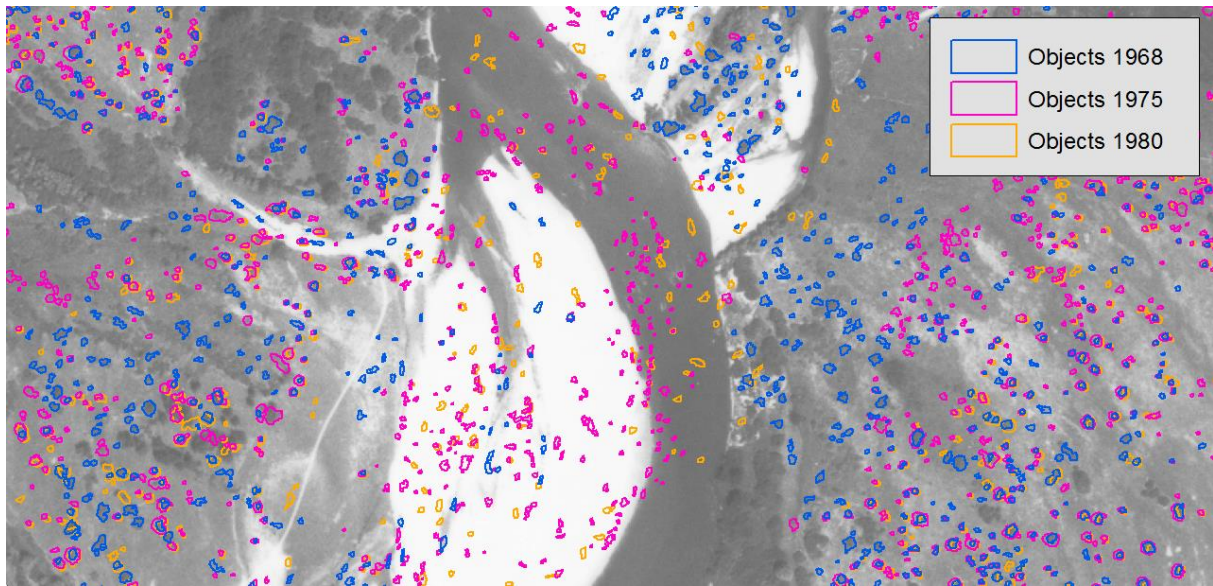


Figure 2.7: Shapefiles of the objects from three images plotted over each other. Full map is present in appendix 1.1

Combination	Years		
1	1968	1975	1980
2	1968	1975	
3	1968		1980
4	1968		
5		1975	1980
6		1975	
7			1980

Table 2.3: combinations of shapefiles intersects of the three years

### 2.5.2 Plotting the information in maps

All the information needed to plot the change in objects is present. In order to plot the changes of objects on a map, the information needs to be ordered and described in such a way that the software can read it accordingly. For this a code will be used. In the object lists new columns will be added with code values which represent surface classes and area and shape index values ranging from 1-9. Each characteristic is divided into 9 intervals in order to assign a code to each interval (Table 2.4). The codes will subsequently be combined into multi-digit code. In this code each digit represents a characteristic of an object. Using this method two different maps are made for the surviving objects and disappearing objects.

For the surviving objects three characteristics of objects are needed to be plot. This is done by combining the codes representing the characteristics to be combined into a three digit code. The first digit represents the class at  $t=1$ , second digit the class at  $t=2$

and the third digit either shape index or area at t=1 (Table 2.5). This code lets us visualize the characteristics of the objects with symbols in three different ways: colour, shape and size. Area and Shape index are represented with a code ranging from 1 to 9. The symbol is plotted with three different sizes, combining codes 1-3, 4-6 and 7-9. Plotting the classes of objects at the start and end of the time step along with either the area or shape index will visualize all information one map.

*Table 2.4: Conversion list of changing area and shape index values to code*

Code	Area (m <sup>2</sup> )	Shape index
1	0 - 10	1.0 - 1.1
2	10 - 20	1.1 - 1.2
3	20 - 30	1.2 - 1.3
4	30 - 40	1.3 - 1.4
5	40 - 50	1.4 - 1.5
6	60 - 70	1.5 - 1.6
7	70 - 80	1.6 - 1.7
8	80 - 90	1.7 - 1.8
9	90 >	1.8 - 2.0

When the same method was used for the disappearing objects, the map became too cluttered with objects due to their large number. So the choice was made to only plot the larger objects and visualize the merging or disappearing of the objects together with the shape index. A distinction was made between the objects disappearing into low vegetation and merging with high vegetation. This means the objects are divided into the colors green for merging with the high vegetation, yellow for disappearing in low vegetation and red for disappearing due to river influences. The shape index was visualized by the size of the symbols. The code for this visualization comes down to the same principle as in the previous map. However, for this map only two digits are used. The first digit represents the new class, and the second digit the shape. With these two maps finished, a tool to observe spatial patterns is available.

Table 2.5: Example of the code used to plot the objects

Object ID	Class t=1 (Colour)	Class t=2 (Shape)	Shape index t=1 (Size)	Combined
1	1	1	6	116
2	3	4	5	345
3	3	4	3	343
4	4	2	3	423
5	1	3	6	136
5	2	2	1	221

### 3 Results

The classification provides a representation of the surface and the isolated objects (figure 3.1). The following analysis provided information on how the isolated objects in the study area developed. Information on the development is divided into surviving objects and disappearing objects. Both groups consist of the isolated object classes: IsolatedSmallBright, IsolatedBright, IsolatedSmallLowVeg and IsolatedLowVeg. They represent the isolated objects which are located within a vegetated background (LowVeg) and objects in a bare background (Bright). They are further divided into small and larger objects as explained in chapter 2.4. Information on the object numbers and class distribution will be discussed first and secondly the spatial distribution of objects.

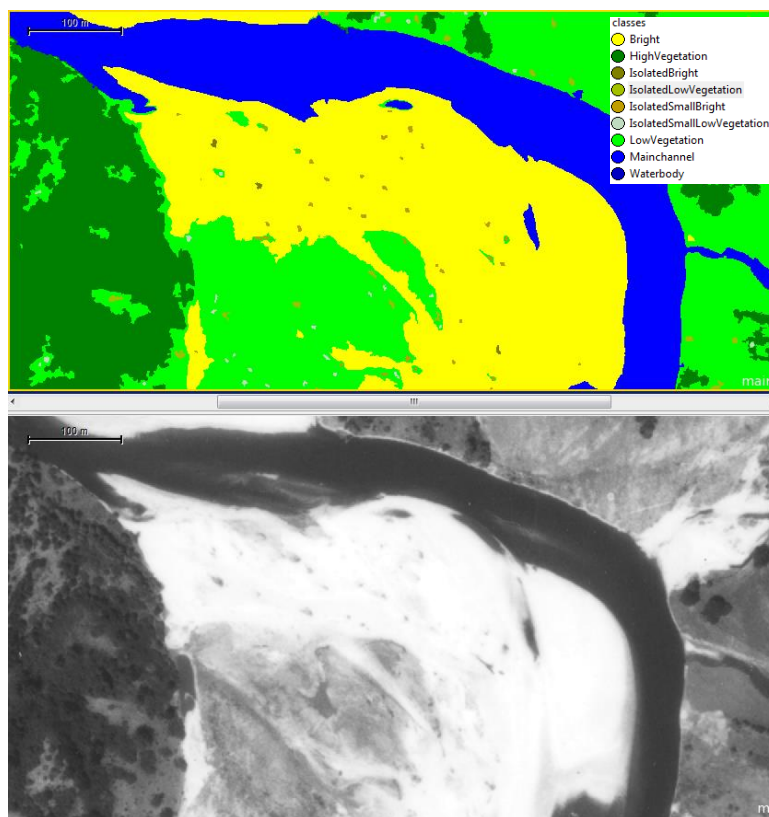


Figure 3.1 Classification of surface classes in the study area

### 3.1 Development of objects

#### 3.1.1 Summary of object numbers

First, the numbers of objects will be presented. As mentioned before, two different groups of objects could be identified: those who remain objects and those who disappear. A summary of these objects gives an overview of the amount of objects and how they change (figure 3.1). The figure is showing the changes an object can make during a time step. The top line represents objects which remain the same class, and the middle one represents objects which change their class. The bottom ones show



disappearing (left) and new (right) objects during a time step. Table 3.1 gives an overview of the objects per subclass. Here can be seen that the overwhelming part of the objects are present in the low vegetated areas.

In figure 3.2 three different time steps are presented. The first two are consecutive time steps 1968-1975 (figure 3.2 A) and 1975-1980 (figure 3.2 B). These diagrams show that a large part of the objects are not seen in the next year. In the first time step from 1968 to 1975, there are twice as many objects which disappear in comparison to the objects which stay. In the time step from 1975 to 1980 it is over double the amount. The third diagram shows the change of objects from the first image to the last one 1968-1980 (figure 3.2 C). In this last diagram can be seen that of the large amount of objects only a small amount survives during the time series. In the following sections a more detailed report will be given of the two main groups.

*Table 3.1: Amount of objects per class for the three images*

Year	IsolatedBright	IsolatedSmallBright	IsolatedLowVeg	IsolatedSmallLowVeg	Total
1968	29	377	326	1350	2082
1975	18	480	590	2916	4004
1980	45	201	425	951	1622

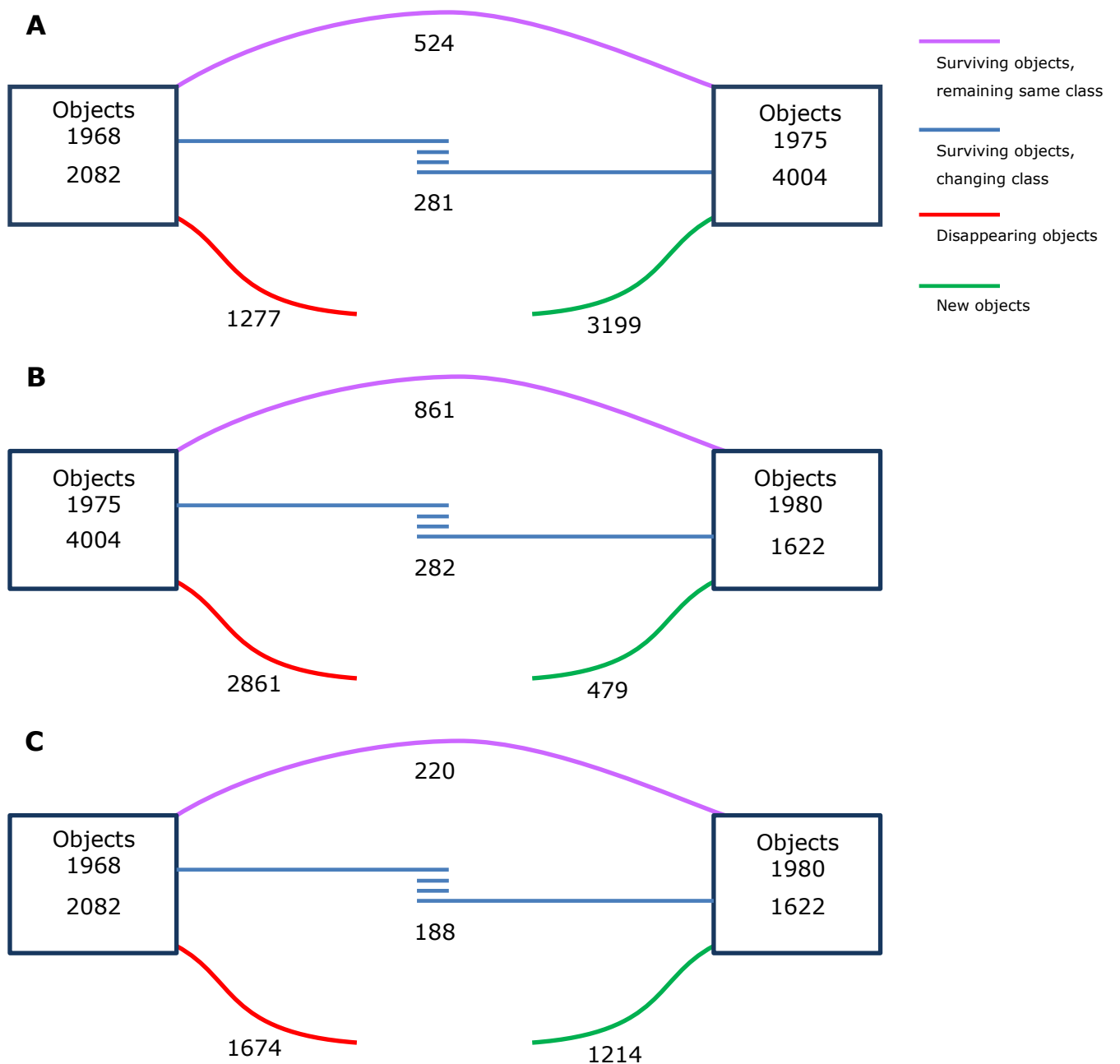


Figure 3.2: Diagram with the summary of the objects during the time steps. A) Time step 1968 to 1975. B) Time step 1975 to 1980. C) Summary of change in objects from the first image (1968) to the last image (1968).

### 3.1.2 Development of surviving objects

Surviving objects are seen either two or three consecutive years. The amount of these objects is smaller than the ones which disappear during the time step as mentioned before. Even though these objects remain objects, their individual class may change (figure 3.3). The diagonal in the table below the chart indicates the objects which retain the same class and is the same as the top line in the diagram (figure 3.2). The first main thing to notice is that the small objects (<math><30\text{ m}^2</math>) are more numerous than the larger objects. Secondly, most objects, small and large, are surrounded by low vegetation.

Objects from class IsolatedSmallLowVeg which change class, change for the largest part to IsolatedLowVeg, indicating growth of the objects. The second class to which most objects change is IsolatedSmallLowVeg with most objects coming from both IsolatedLowVeg and IsolatedSmallBright. These trends are seen in both time steps. More noticeable in the first time step then in the second one is the large relative change from IsolatedSmallBright to IsolatedSmallLowVeg which indicates succession.

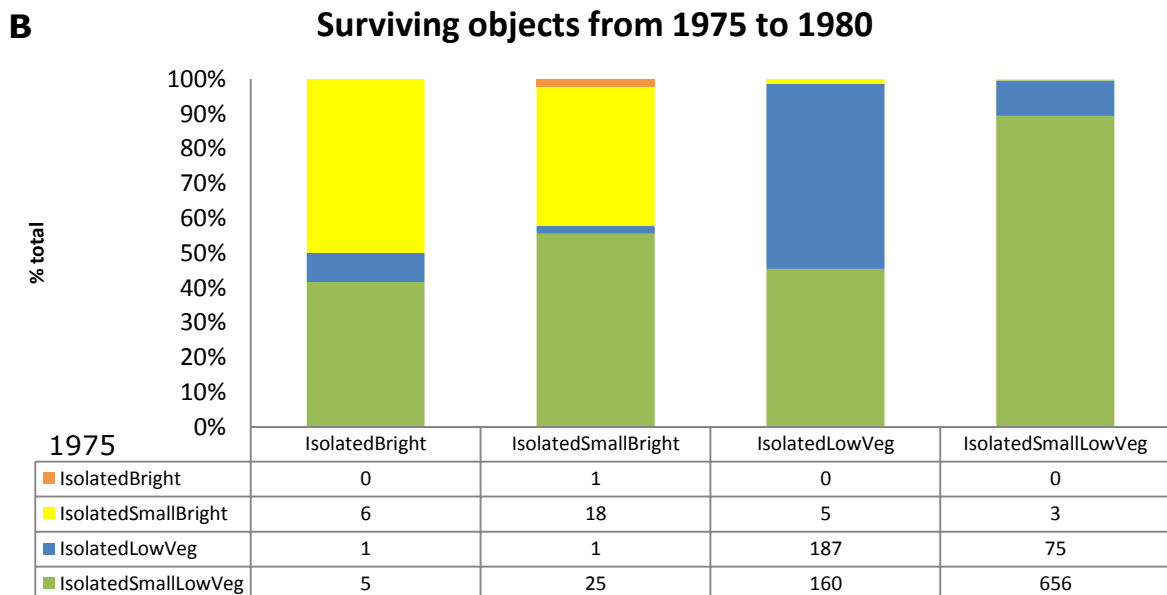
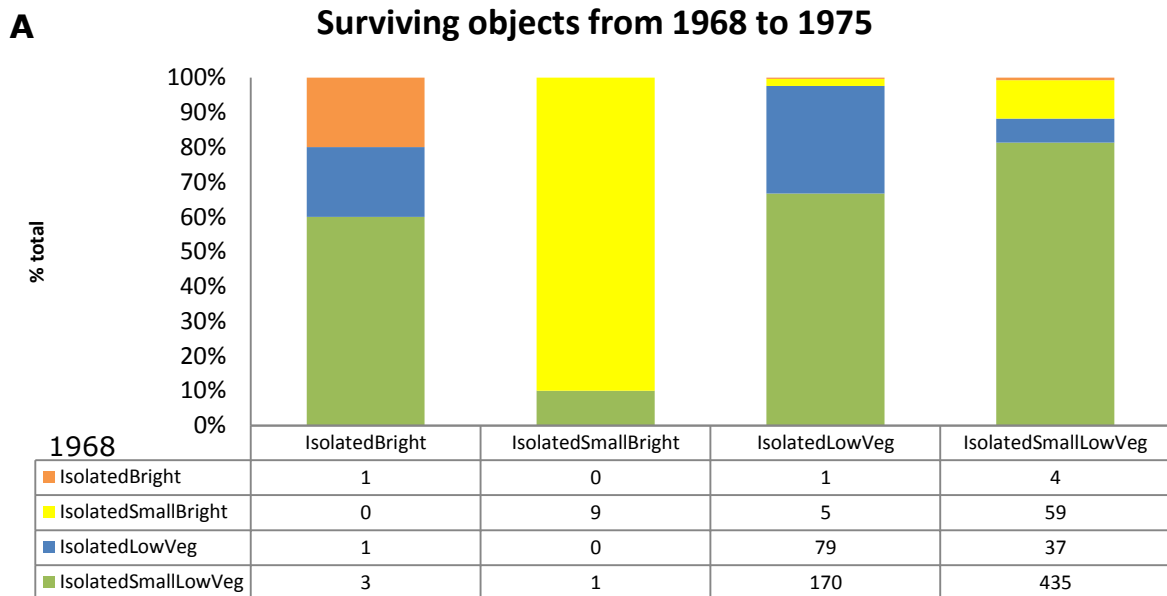


Figure 3.3: The change in class of surviving objects during the two time steps A) 1968-1976 and B) 1975-1980. Graph A shows how an object changes from 1968 (classes at the left side of the table) to 1975 (classes along the top side of the table). Same for B, for 1975 to 1980.

408 objects survive both time steps, and thus show information on changes in classes during two time steps. To see the development of these objects, the change in classes is visualized for the paths they can take (figure 3.4). Each class can change to four different classes during a time step. This means that starting from 1968 to 1975 there are sixteen different pathways and sixty-four from 1975 to 1980. The amounts of pathways used are seven out of sixteen until 1975 and fifteen out of sixty-four until 1980. This indicates the change in objects is mainly towards the objects surrounded by vegetation. The class variety in 1980 indicates that class variety does not necessarily need to decrease as time goes on.

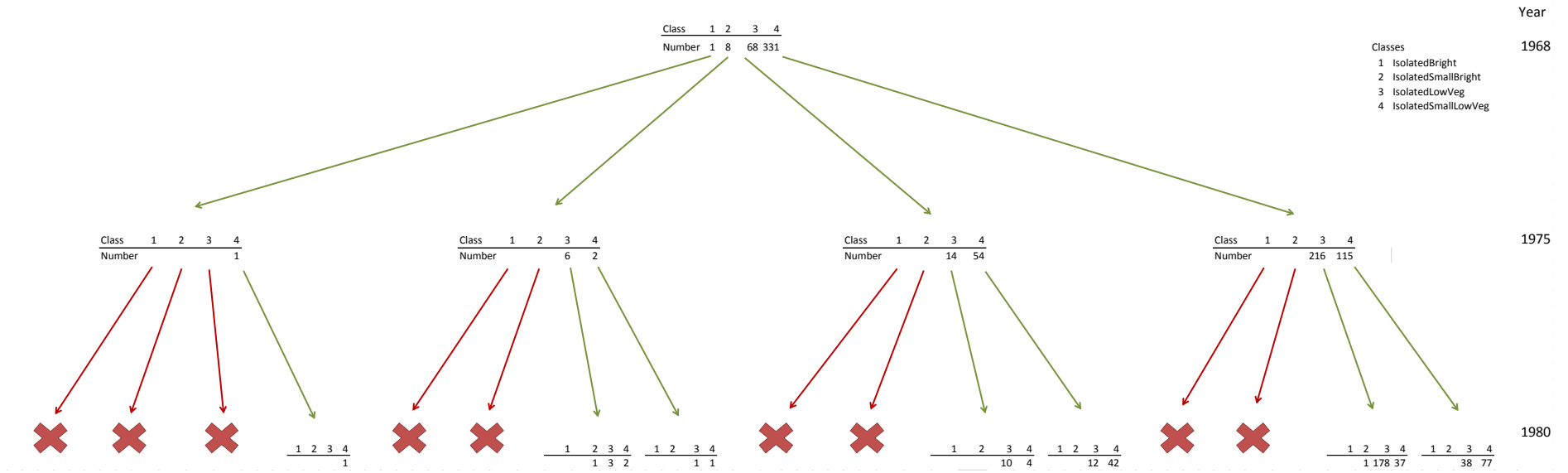


Figure 3.4: Development tree of objects occurring in all three images. The arrows show the changes objects make during time steps.

### 3.1.3 Development of disappearing objects

Disappearing objects disappear either through influence of the river or by becoming part of the vegetation classes. The numbers of these disappearing objects are higher than the group discussed before and are for large part small objects. Just as in the previous group the largest class is the IsolatedSmallLowVeg with about 60-70% of the total amount of objects (Figure 3.5). The change from object to surface class is presented in the two graphs below. The objects change into the surface classes we defined in chapter 2.4. As can be seen in the graphs, the class which takes up almost half of the disappearing objects is LowVeg. Looking at the numbers we can see that the changes in both time steps show similar values for the surface classes they change into. The MainChannel and Bright classes take up similar percentages of objects in both time steps (table 3.2).

*Table 3.2: distribution of disappearing objects over the surface classes they change into*

Time step	Percentage of total disappearing objects taken up by surface classes				
	LowVeg	HighVeg	Bright	MainChannel	Waterbody
1968-1975	44.5	28.7	17.2	9.6	0
1975-1980	53.3	14.4	21.2	10.5	0.6

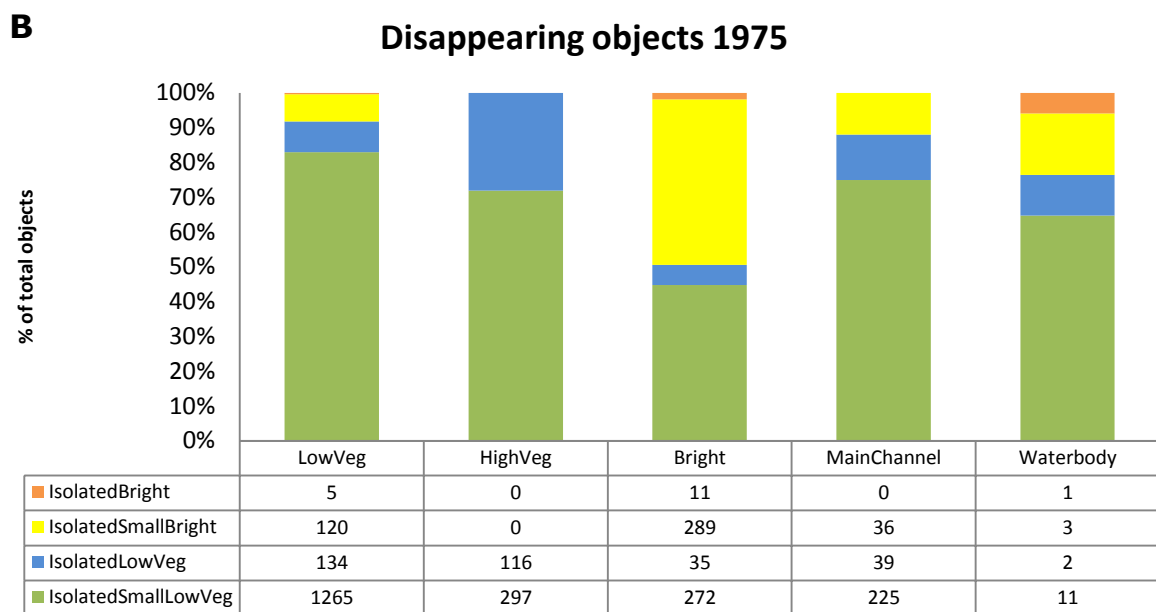
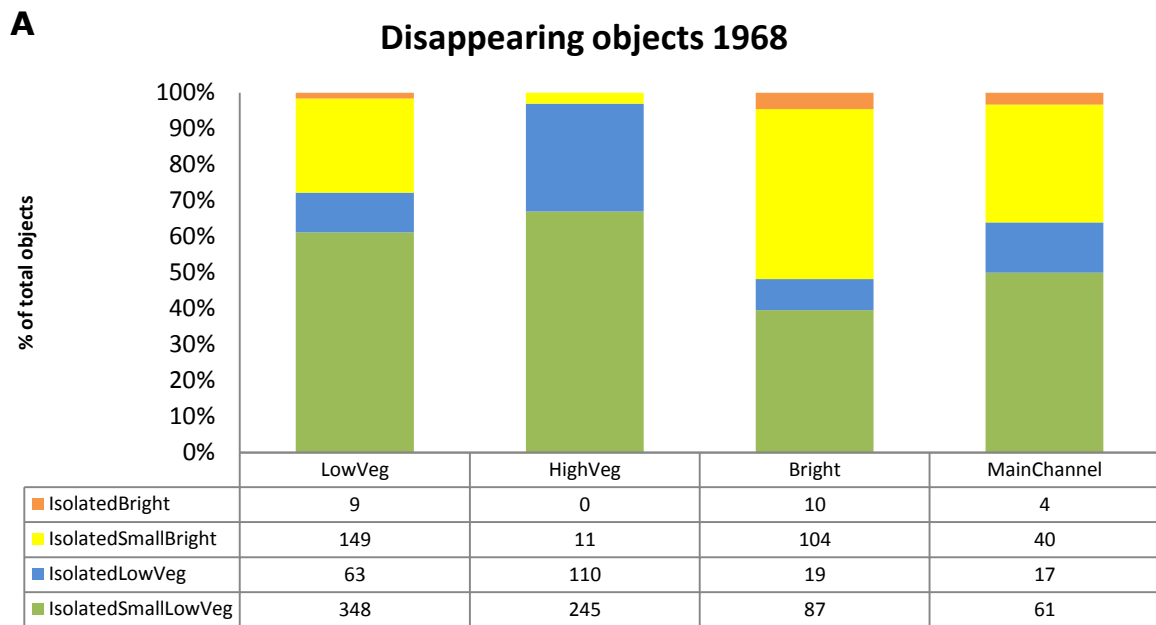


Figure 3.5: Disappearing objects in 1968 (A), and 1975 (B). The original class of the disappearing objects is indicated at the left side of the table. Along the top side of the table the resulting classes are presented.

## 3.2 Spatial patterns in isolated objects

Objects are plot in maps visualizing information on spatial distribution and on the area and shape of an object. The first maps which are presented are maps which show the relative age of objects derived from the analysis. In the other maps the difference is made between the surviving objects and disappearing objects. These two groups have been plotted in a map to observe the spatial distribution of the different classes. For

observing patterns in characteristics of objects these are plotted along with the object characteristics so spatial patterns can be observed. For each group there are two time steps plotted for both the area and shape index. As was explained before the maps contain information on the classes at both  $t=1$  and  $t=2$  and the area or shape index at  $t=1$ . In this manner one can observe where the changes, seen earlier in numbers, happen in the study area. Having the area and shape index represented by the symbols one can observe if there are relations between location and these characteristics. In the following sections examples from the main maps are given, full maps are present in the appendix.

### **3.2.1 Relative age of objects**

For all objects their relative age is plotted (figure 3.6, full size maps in Appendix 2). New objects are plotted with green symbols, and objects which occurred in the previous years will gradually be plotted more dark as they become older. The remaining objects, which are only present at this point in time, will be plot with red. These maps are a summary of the two groups of objects and give insight in where new objects appear, and where existing objects either stay or disappear.

What we see in these maps are clusters of objects which remain fairly stable in the older meander bends and show an increasing relative age (figure 3.6, orange arrow). New objects tend to appear most often in areas of the floodplain where water is likely to flow during flooding (Blue arrows). What these maps also show is that objects are at risk of being destroyed at a close proximity to the river regardless of their age. So objects are at risk in the areas affected during flooding, and at the areas at the outside of a meander due to meander migration.



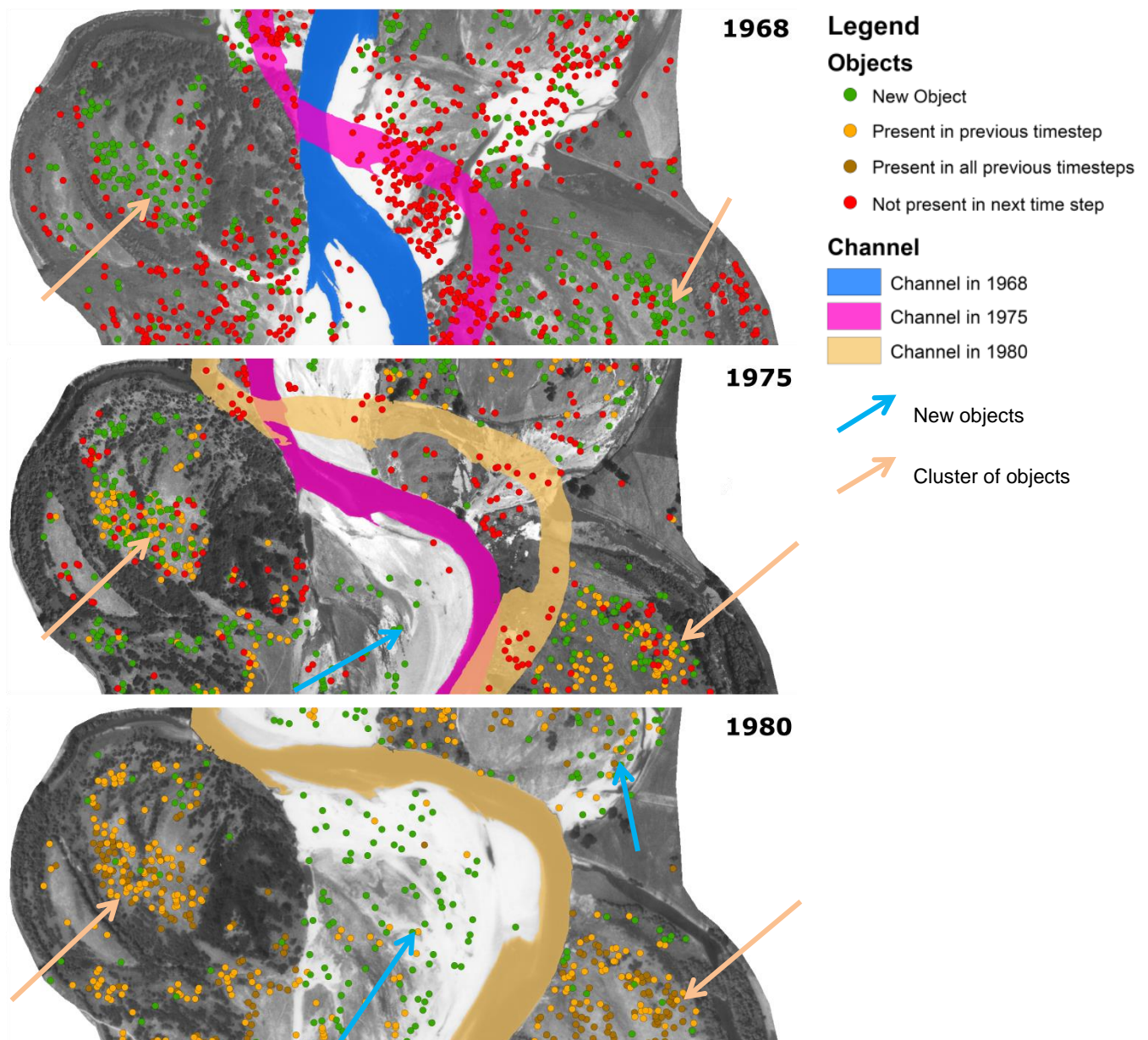


Figure 3.6: Subsets of the maps with the relative age of objects plotted. Yellow arrows indicate clustering of older objects. Blue arrows indicate new objects in the floodplain.

### 3.2.2 Patterns in surviving objects

Surviving objects are presented for two time steps in maps for both area and shape index at  $t=1$  (Figure 3.7, complete maps in Appendix 3). Noticeable is that there are less objects near the river and most objects seem to be clustered on the older point bar relics in old meander bends. This is indicative of more stable conditions further away from the river.

In these maps can further be seen that the area of an object is not necessarily related to the location of an object (figure 3.7 A). This suggests that the distribution and growth of the objects in the study area is relative random and not a function of distance to the river. The maps with shape index visualized show the same randomness as with

the area (figure 3.7 B). The spatial patterns in size and shape distribution seem to be quite random from these results.

Ignoring the characteristics like area and shape the objects do seem to form some patterns (figure 3.8). In multiple locations they form lines along the flow direction of the river. These lines are seen on either point bar (figure 3.8 A), and more vegetated areas (figure 3.8 B) On the old meander bends the pattern changes to a more clustered formation (figure 3.8 C).

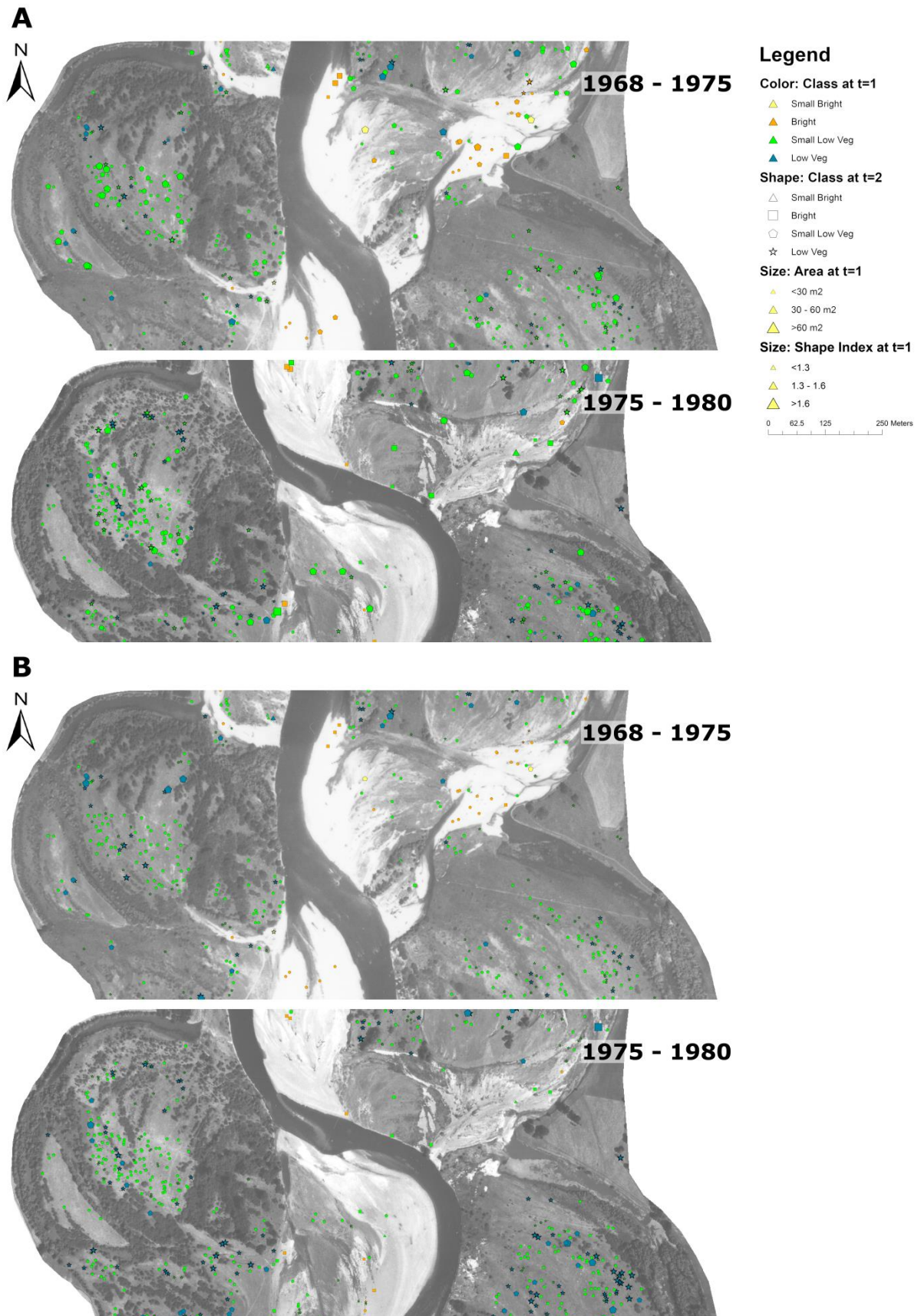


Figure 3.7: Subsets of maps visualizing objects to objects. Showing the objects to objects during the two time steps with characteristic Area in A, and characteristic Shape Index in B.

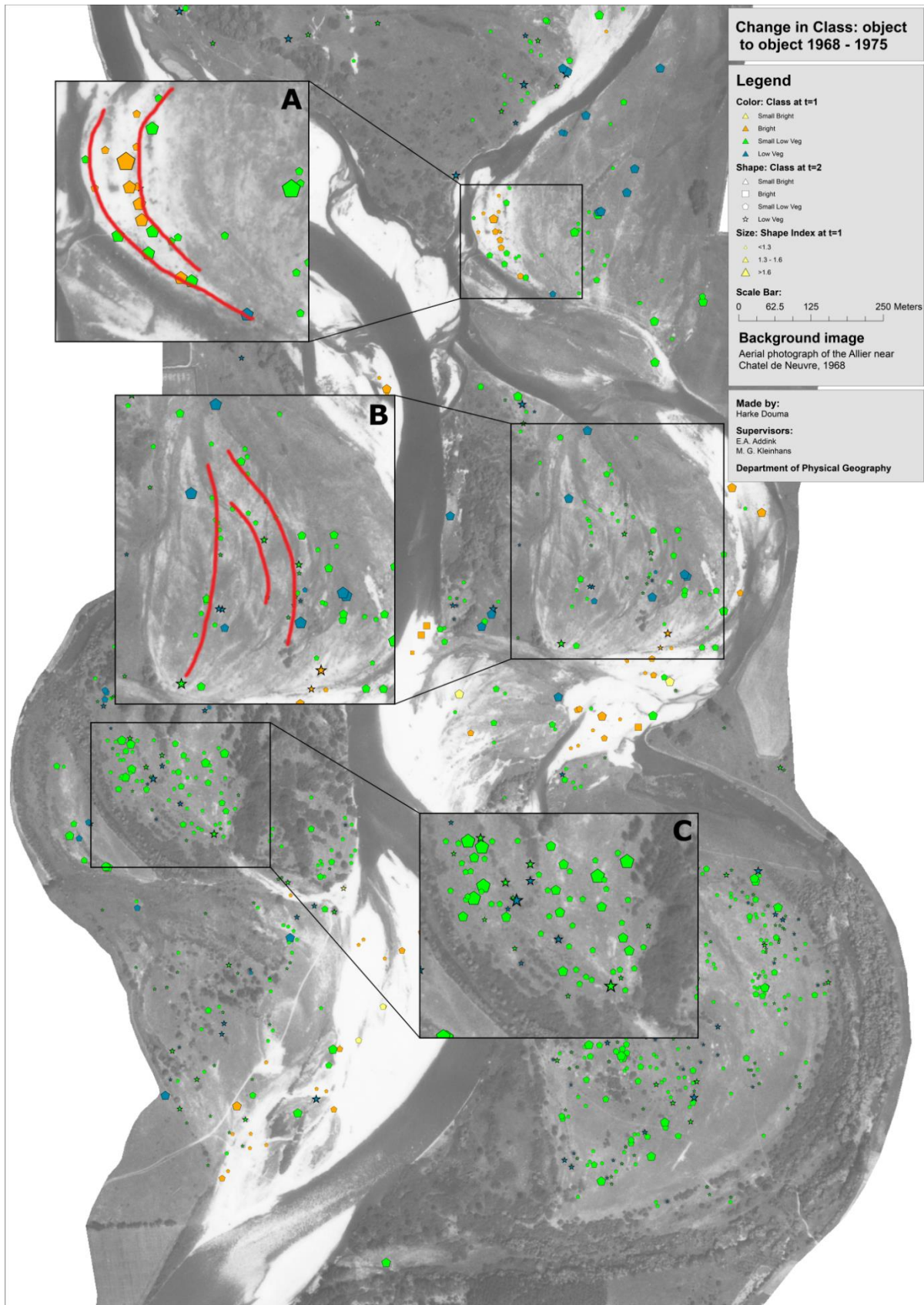


Figure 3.8: Visible patterns in isolated objects. Lines and clusters are visible in the isolated objects at different locations. A) Lines on a small point bar. B) Lines of objects in a more vegetated area. C) Cluster of objects on an old meander bend.

### 3.2.3 Patterns in disappearing objects

For the disappearing objects only the larger disappearing objects are plotted. This is because by plotting all disappearing objects the map became too cluttered. In figure 3.9 can be seen where the large isolated objects disappear (full maps in appendix 4). Red objects are objects disappearing into either channel, or bare surface. Objects indicated with green are taken up by the high vegetation class patches and the yellow ones are changing into the low vegetation class.

The red dots are mostly located near the channel, and in the lateral path the river moves during the time step. Some red dots appear further away from the river (figure 3.9, blue arrow). The presence of sand and small channel remains indicate this area is regularly flooded during high water. The other disappearing objects have less clear causes and are also more spread over the study area. The objects that are near high vegetation patches often merge with these patches.

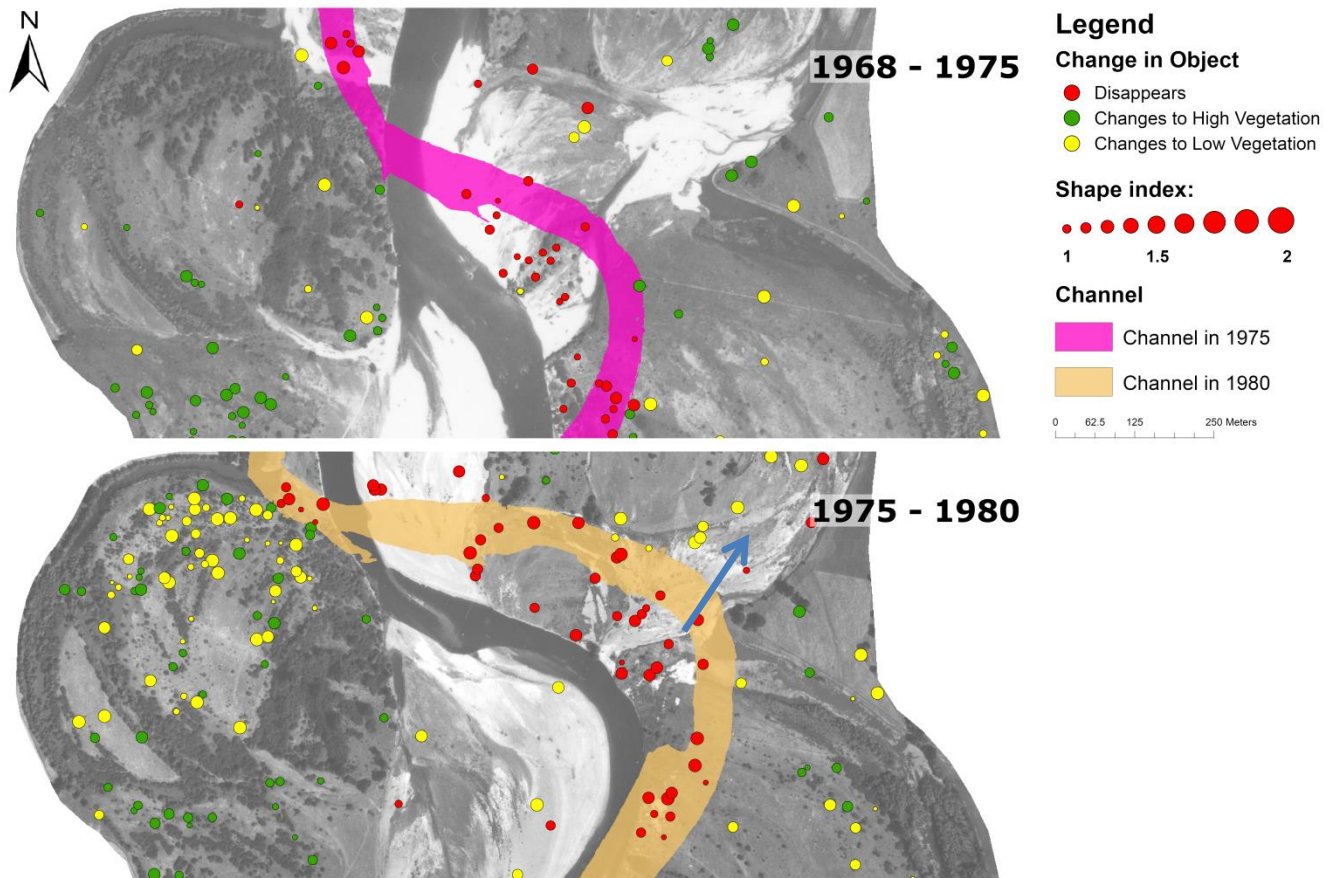


Figure 3.9: The large disappearing objects plotted in a map for the two time steps. The blue arrow indicates disappearing objects further away from the main channel.

#### **3.2.4 Scatterplots of object characteristics**

To see if there were patterns or relations between the different characteristics, which might not be seen directly in the maps, scatterplots were made (figure 3.10). These scatterplots show the same what was seen in the maps, which is that there is no clear relation between the three characteristics. Area and shape index show a random distribution in relation to the distance to river (Figure 3.10, B and C). A relation between the area of an object and its corresponding shape index is also non-existent.

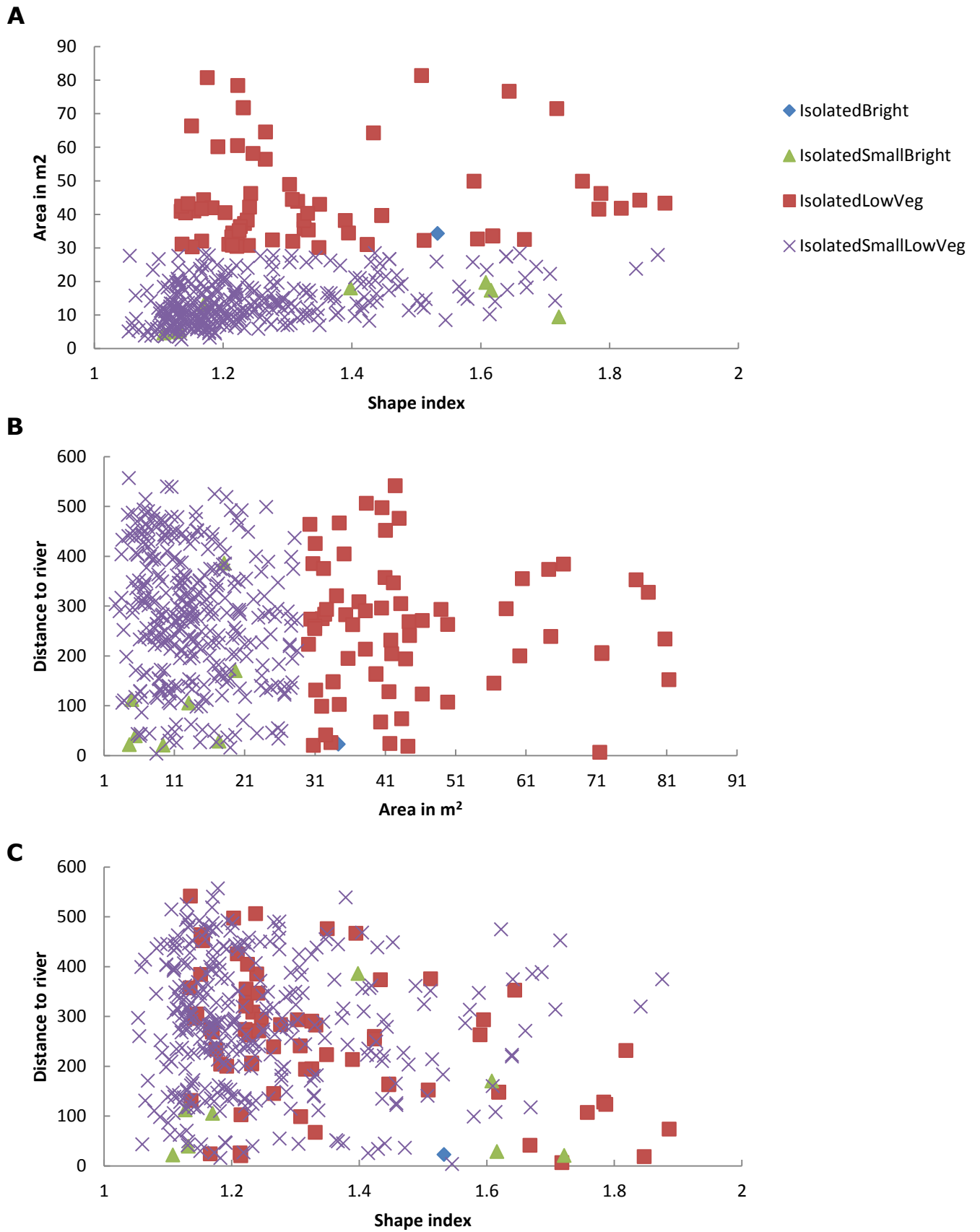


Figure 3.10: Surviving objects (1968-1975-1980, time step 1968-1975). A) Area vs Shape index, B) Distance to river vs Area, C) Distance to river vs Shape index.

## **4 Discussion**

### **4.1 Methods**

The method of extracting isolated objects from riparian vegetation in aerial photographs was developed for this research. The aerial photographs were digitized and orthorectified in order to enable further classification of images in software and analysis in GIS. Choices in the process of developing the method may have influence in the end result.

#### **4.1.1 Effect of orthorectification**

Orthorectification resamples the photography to images where pixels have a known size, and distortions caused by elevation differences removed. Since the removal of distortions is done by a DEM of not very high quality positional errors will remain in and between images. This may result in objects not having the exact same location in different images. By intersecting the objects in GIS, this error is diminished for most of the objects as even a small overlap is enough to track the object through the images.

#### **4.1.2 Choices for the classification process**

The classification is done by using object based image analysis (OBIA), which opens a wide array of possibilities for classifications. Using rule-sets with segmentation and classification rules one has endless ways of classifying an image. There were some different methods that were tried in this research.

One method that was tried was classification based on using multiple segmentation layers. Since the imagery consists only of grayscale photography, use of shape and texture becomes more important. This method relies on having smaller objects within larger objects where the composition of smaller objects within the larger object determines structure. Using this would probably enable the ruleset to distinguish between river and vegetation. However, within the available time this method did not deliver desirable results.

Another option that was tried was template matching. With this option one creates a template of an object which needs to be located throughout the image. At first this seems a technique suitable for locating trees and shrubs. In practice however, template matching performs badly with the images of the study area. Too often the template matched with locations which had no visible trees or shrubs. Reasons for this could be the resolution of the images and or inexperience using the tool. Optimizing the technique for this application was not the goal of the research so it was abandoned.

What worked in this research was using a semi-automatic approach in which certain parts of the image were classified manually. River and water bodies were classified manually due to the similarities between dark vegetation. Manual classification was not the most elegant solution, though considering the objective of the study and the allotted



time this was however the easiest solution. The trees and shrubs as darker isolated objects were found to be able to be extracted with relative ease using the relation of bright objects surrounding darker objects. The combination of these methods worked very well and made the classification possible.

#### **4.1.3 Classification results**

The method was developed to extract vegetation from aerial photography. The grayscale photography set some limitations on interpreting surface classes. Combined with the focus on isolated objects the variety in the vegetation classes was kept at a minimum. This resulted in pretty coarse vegetation classes: low vegetation and high vegetation. The accuracy of the vegetation classification in regards to low and high vegetation is hard to check. Since the only way these two vegetation classes are distinguished from each other is based on the brightness. The tricky part with the classification based on brightness is that in aerial photography the brightness at the center of a photograph is usually higher than at the edges. This leads to differences in an image by setting a threshold which is representing surface cover differently throughout the image. These differences might lead to differences within an image and even differences between images which might not be there. This effect can lead to high or low vegetation be wrongly classified. Places where this influence was seen most are the old meander bend in the southwest part, and north in the center of the study area.

Extracting isolated objects is an automated process. This means that some objects we indicated as isolated objects may not represent an isolated shrub or tree. This error becomes less important when an object is seen throughout multiple years. Having this confirmation that an object is correctly classified as an isolated object is an indication that the extraction works well. It also makes these objects seen over a longer time more interesting than the objects seen only in one image.

#### **4.1.4 Object analysis**

When summarizing of the object numbers it became apparent that the number of analyzed objects was inconsistent with the original starting objects in the exported shape files (table 4.1). When comparing the total objects from the shape files with the total object numbers from intersects, it indicated an overestimation each year. In order to find where these inconsistencies come from the numbers from the different subgroups were checked. The group objects to objects had a consistent number with analyzed and original numbers from intersects. The group that showed differences was the disappearing objects. In 1968 there is a difference of almost 200 objects, though in 1975 this difference is only 4. This means that something went wrong in exporting the objects after intersecting them with the classification. Due to time constrictions and the error being in the least interesting group this error was not corrected. However, this problem

showed that using the intersecting tool will create more objects when certain object shapes will create two new objects instead of just one.

*Table 4.1: Inconsistencies in total object numbers at certain points of the analysis. The different totals indicate possible flaws in the analysis method.*

Year	Original shapefile	Intersect totals	Analyzed totals
1968	2236	2263	2082
1975	3943	4008	4004
1980	1596	1622	1622

## 4.2 Object development

### 4.2.1 Object numbers

By analyzing the objects from the shapefiles of the three images, a large amount of data on the numbers and characteristics of objects was obtained. The numbers provide an indication on the distribution of their classes and the flow of objects between them. In the results we saw that the largest amount of objects were present in the low vegetation class for both staying and disappearing objects. This suggests that isolated objects are forming more easily in the areas with low vegetation instead of surrounded by bare soil. The high amount of disappearing objects suggests dynamic conditions in the vegetation development.

### 4.2.2 Disappearing objects

Disappearing objects are objects which are not seen as isolated objects in the following image. There can be a few causes for a disappearing object. First, the objects and the vegetation it represents have disappeared due to river influences. This is most obvious when there is a river flowing where in the previous image objects were present. It is assumed that the same fate fell to the disappeared objects which are now bare soil as the river influence is significant at the point bars.

Disappearing objects do however not always mean that the tree or shrub it represents has disappeared. It is possible that a tree or shrub grow towards each other, or towards a patch of high vegetation. When this happens the tree or shrub does not fit the requirements for an isolated object anymore and thus the object disappears. The isolated object changes into high vegetation in this case.

The next possibility has a less obvious cause. When objects change into low vegetation the object is not recognized the next image, but does this mean the vegetation it represents is gone? As we cannot check the images with reality it is

assumed that these isolated objects and the vegetation it represents have disappeared. A clear cause for the disappearance cannot be found from the data in this research as the temporal resolution is too low. Possible causes could be natural dying, flooding or grazing.

Next to the more natural causes for the disappearance of objects there is the influence of different brightness between the images. As was mentioned before, brightness between images can be different for parts of the study area. With classification this can lead to overestimation of the high vegetation patches. This in turn removes possible candidates for isolated objects as they are now part of a high vegetation patch. As brightness levels may be different between images, an object being an isolated object in image 1, may not be seen as an isolated object in image 2. The object will have disappeared although in reality it is still an isolated object. To summarize the different possibilities:

- The object merges with high vegetation patch
- The object is destroyed under influence of the river
- The object dies "naturally"
- The object disappears due to image differences in classification

However, the temporal resolution of the data used is too low to make clear conclusions on how each object has disappeared. Only assumptions can be made.

## **4.3 Spatial Patterns**

### **4.3.1 New objects**

We were interested in seeing if there were spatial patterns to be seen in the distribution of the objects. Looking at only the relative age of the objects certain patterns could be distinguished. In particular the maps of 1975 and 1980 are of interest (appendix 2.2, 2.3), since as 1968 is the first image technically all objects are new. In 1975 there are a lot of new objects throughout the whole image. This is caused for a part by the higher resolution of that image which made it easier to recognize isolated objects. There are still a lot of new objects which appear in the areas which flood during high discharge. This trend is more clearly seen in 1980 where most of the older objects have already been seen before. The new objects are mostly located on the point bars and along an abandoned channel seen in the western part just above the center (appendix 2.3). Seeing most of these new objects appearing in the flooded areas strongly suggests that the spread of seeds is mostly hydrochorously. This seems to agree with conclusions on in situ research done by Corenblit et al. (2016) on seed retention by pioneer vegetation. Data on new objects shows a random pattern in the distribution of new objects on the

floodplain which suggests that most seeds just seem to randomly drop somewhere and sprout.

As there are new objects there are also objects seen continuously for two or even three years. These objects are seen for the most part on the older meander bends, or oxbow lakes. Influence from the river is much lower here than on the point bars and areas which are regularly flooded. Conditions here are more stable which means vegetation like trees and shrubs have more chance of surviving. On these locations there seems to be a balance in which both low, high vegetation and isolated objects coexist.

#### **4.3.2 Spatial patterns in size and shape of isolated objects**

To see if area and or shape of an object had influence on the development of an object and thus would result in certain spatial patterns, the objects were plotted along with their area or shape index in the maps. One would expect the area of objects to be related to the position of the objects in relation to the river. To a certain extent this is true as objects occurring in point bars are relative small. However, at locations further from the river both large and small objects occur throughout the time series. There are no obvious patterns visible with relation to the area of an object and its location. The shape index gives the same suggestion that there is no clear relation between the shape of an object and its location. What can be concluded from this is that there is no significant relation between the two characteristics and their location.

This conclusion is supported by the scatterplots which plot the characteristics vs each other and the distance to river (figure 3.10). There are no trends visible in these plots that would indicate a relation between these characteristics.

After determining that these characteristics do not hold lot of value, we took another look at the maps but ignoring area and shape. One can see that the objects form patterns in certain parts of the study area. The main goal of this study was not to measure and quantify these patterns. So these patterns are observed but further analysis has not been conducted. To conclude, isolated objects do form patterns like lines and clusters, though the shape and area of objects does not seem to have any influence.

## **4.4 Succession in vegetation**

Geerling et al. (2006) identified succession of riparian vegetation ecotopes in the Allier river system. The succession of an ecotope can have different beginning features, though every succession starts anew when swept clean by the river. Forest and bush for example emerge most often from channel remains, whereas grass and herbaceous vegetation emerge on bare soil (figure 2.1). In the analyzed study area we found the vegetation types to be following these succession patterns. We found mainly high vegetation (forest and bush) in the oxbow lakes and low vegetation (grass and

herbaceous vegetation) on the old point bars. This means that we could now produce information on the vegetation along with the succession of vegetation types.

Isolated objects were extracted from low vegetation and thus mainly capture the dynamics and development in the succession starting with bare soil. The data suggests that the succession ends in a balance where low vegetation like grasses and herbs remain alongside trees and shrubs on the older point bars and stays mainly open. This was also observed by Van den Berg and Bulyak (2004). Some locations seem to suggest that some parts can grow closed, though the time series this study analyzed is not long enough to document those changes. For now this time series is too short to say anything conclusive, but it seems to agree with earlier observations.

#### **4.5 First step in validating model results**

Now we have these results, the question is how they relate to the problem stated before. What can we do now which we couldn't do before? Studies like Van Oorschot et al. (2015) produced results on vegetation dynamics and patterns but there was no way to validate these results due to a lack of ground truth data. Geerling et al. (2006) indicated the dynamics between ecotopes during succession, though information on the vegetation itself was lacking. This means that although the information is valuable, comparing vegetation dynamics and patterns from model results is not possible.

What this research provides is a method from which information on vegetation can be obtained. Having information on the spatial distribution and development of vegetation on the level of single trees and shrubs provides a first step in comparing model results to real life situations.

## 5 Conclusions

The goal of the research was to determine the spatial and temporal development of isolated vegetation objects. In the introduction research questions were stated to help with achieving this goal. By developing a method to extract vegetation objects from aerial photography and analyzing development of these objects in GIS, these research questions can be answered.

To gather information on the development of the vegetation historical aerial photography from 1968, 1975 and 1980 was used. A method was developed to go from photography to analyzing the contents in a GIS environment. After digitizing the photography, object based image analyses was used to classify the land cover and extract isolated vegetation objects. The exported shape files were subsequently used in GIS where the development of objects could be analyzed. The resulting groups of objects were plotted in maps where possible spatial patterns could be observed. The method is successful in extracting isolated vegetation objects from grayscale historical aerial photography. Despite differences between the images many objects could be extracted and traced throughout all three analyzed images.

To determine the development of the objects they were analyzed in GIS. This showed three groups: surviving objects, disappearing objects and new objects. The largest groups are the disappearing and new objects. Over 50% of the objects will disappear during a time step. This indicates a dynamic environment where objects will not stay long term but rather yearly or seasonal. Surviving objects are only a small part of the total amount of objects. The biggest share of objects were located within a low vegetated background, or changed from a bare background to low vegetated background as was seen especially in the surviving objects.

For determining the spatial patterns the objects were plotted in maps where different characteristics were visualized. A map in which the relative age of objects was plotted shows the spatial distribution of objects from the three groups. The map from 1980 shows most clearly that surviving objects are seen in the areas further away from the channel, like the abandoned meander bends, and new objects mostly appear in the areas closer to the river where flooding occurs. This suggests that the seeding of new vegetation happens mostly due to seeds transferred by water.

Disappearing objects were seen throughout the study area, though there is a clear distinction between the spatial distributions of the different causes. Close to the river these objects disappeared due to meandering of the river and most likely flooding. Objects close to high vegetation patches disappear mainly by merging with these patches. Objects disappearing into low vegetation have a less clear cause, dying by water shortage and grazing are possibilities.

Next to relative age characteristics like area and size were also plotted. These characteristics showed no relation with the location relative to the river and spatial distribution of objects. This suggests area and shape do not have any significant influence in the formation of spatial patterns of objects. Ignoring area and shape the objects do seem to form patterns like lines and clusters, though are merely visually observed and are not analyzed during this research.

This research developed a method in which isolated vegetation objects are extracted from aerial photography, and thereafter analyzed for temporal development and spatial patterns. The results of this research provide a first step in acquiring the data needed to validate model results.

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