

PHYSICAL CHARACTERISATION OF RIVER CORRIDORS FROM ORTHOPHOTOS: CHALLENGING ISSUES AND FIRST APPLICATION TO THE RHONE HYDROGRAPHIC NETWORK

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ABSTRACT:

According to the Water Framework Directive (WFD), "good ecological status" of all aquatic environments should be achieved by 2015. To validate this objective, we set up management tools to assess the physical condition of rivers. To avoid field work, which is a long and tedious work, and in order to achieve homogeneous data throughout the network, we created geomatic tools based on an object-oriented approach. We made a series of tests on the basin of the Rhône River (France) to assess the feasibility of extracting information from high resolution photographs so as to set up indicators of riverscape and aquatic habitat patterns. We present two examples of applications, one based on a sample of reaches within the catchment for typological purpose and one based on a single reach to highlight its longitudinal structure. The first example concerns the characterisation of braided rivers. The sites assessed are distributed throughout the Rhône basin (France). The second example concerns the study of fish habitat along the Drôme River (a tributary of the Rhône River).

1. INTRODUCTION

The objective of the Water Framework Directive is to achieve by 2015 a good ecological status of all natural aquatic environments, so called "water bodies". This good condition is evaluated from biology that results in part from the physico-chemical conditions and hydromorphological characters. Thus if experiences in terms of water quality assessment and monitoring are now well known, tools are needed to characterize hydromorphological conditions at large scale (i.e. large basin, entire hydrographic network).

In recent years much progress has been made in remote sensing. These advances are interesting for the characterization of a river network at several levels:

- At the local scale, improvements in terms of spectral and spatial resolution allows extraction of high-quality information by limiting the data collection in situ.
- Automation of methods for extracting information allows homogeneous results on the entire network.
- The available data sources are numerous, varied and they can permit to characterize the entire national territory.

The aim of this paper is to test the capacity of an oriented-object method to provide metrics (semi-) automatically to characterise the geomorphology of rivers. These metrics are then calibrated and are used as indicators. Here we present two examples of metrics:

- Metrics which describe the spatial structure of the fluvial landscape (natural corridor and active band).
- Metrics which permit to identify the fish habitats.

We want to find methods that are easily transposable from one site to another in the same area and / or along the hydrographical network.

Our method has focused on the oriented object approach. It is a method which characterizes the object by its radiometric value, its shape, its texture and its context. This is particularly valuable compared to other methods that use only the pixel radiometry. Results obtained with the oriented-object method are close to those obtained from photo-interpretation. The method of object-oriented classification is done in two phases (Wong *et al.*, 2003):

- Segmentation, a priori identification of images objects composed of several pixels (Perez Correa, 2004).
- Classification by clustering the objects in which data structure and spectral behaviour are identical.

In the paper, we used two softwares: Envi ZoomTM and Definiens[®].

The tests presented were conducted using data from the "Rhône Méditerranée Corse (RMC)" hydrographic network managed by the RMC Water Agency. The network includes all French rivers flowing into the Mediterranean Sea. This territory covers an area of 125000 km². The main river network is about 45,000 km long.

We have worked with two different approaches representing two different scales of analysis: a synchronic inter-site comparison at the overall river network scale, and an analysis of longitudinal structure of the aquatic habitats at a river corridor scale.

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2. GENERAL METHOD - RAW DATA AND IMAGE PREPARATION

The raw data used for this work study are vector and raster data. They are extracted from the French Geographic National Institute (IGN, "Institut Geographique National") (Table 1). One objective of this work is to generalize the method for the whole network of the Rhône basin. But unfortunately the weight of each image is heavy and thus using aerial photographs of the entire basin is problematic in terms of processing time and storage (Table 2). Consequently we decided to limit the image size to the valley bottom following the process used by Alber & Piégay (*in press*).

Table 1. Summary data

| BD Alti® | BD Ortho® | BD Carthage® |
|---|---|---|
|  |  |  |
| Digital Terrain Models (50 m) | Orthophotography (50 cm) | Hydrographic referential |
| Raster | Raster | Vector |
| IGN | IGN | IGN, MEDD and Water Agency |

We used the orthophotographies of the BD Ortho® because the data covers the entire network of the Rhône. We can therefore extract the same type of information anywhere. Moreover the BD Ortho® has a high spatial resolution.

Table 2. Characteristics of the BD Ortho®

| General | |
|-----------------------------------|---|
| Spatial resolution | 50 cm |
| Spectral resolution | Visible (red, green, blue) |
| Acquisition frequency | Every 5 years |
| Size | 5 km * 5 km or 1 km * 1 km |
| Acquisition dates | Between 2003 and 2006, according to the departments |
| Network Rhône Mediterranean Corse | |
| Number of images | 6347 |
| Weight of images | 300 Mo (10000 * 10000) |
| Total weight | 1,9 To (1900 Go) |

3. BETWEEN SITES CHARACTERIZATION OF RIVER CORRIDOR LANDSCAPE AT REGIONAL SCALE

3.1 Studied reaches

For the inter-sites analysis of the spatial structure of river corridor we selected 50 braided reaches in the Rhone basin (Figure 1).

In the RMC hydrographic network several gravel braided reaches remain (650 km) despite their widespread disappearance since big infrastructure construction in the 19th century (Piégay *et al.*, 2009). Braided rivers are characterised by a high spatial variability both intra and inter-sites.

Selected reaches are located from north to south in the RMC river network and cover a wide range of altitude (715.5 m on

average), slope (from 2.8 to 52.5 m/km) and drainage area (421.31 km²). River regime is variable from glacial systems in the highest mountainous reaches to Mediterranean river regime towards the south. The length of a reach has been determined as 20 times the active channel width (Slater, 2007), where the active channel is the area occupied by water channels and gravel bars.

Reaches have been selected further to image availability and quality and to achieve a wide geographical representativeness; the extraction of spatial metrics starting from aerial photos of sites regionally spaced could be tested.

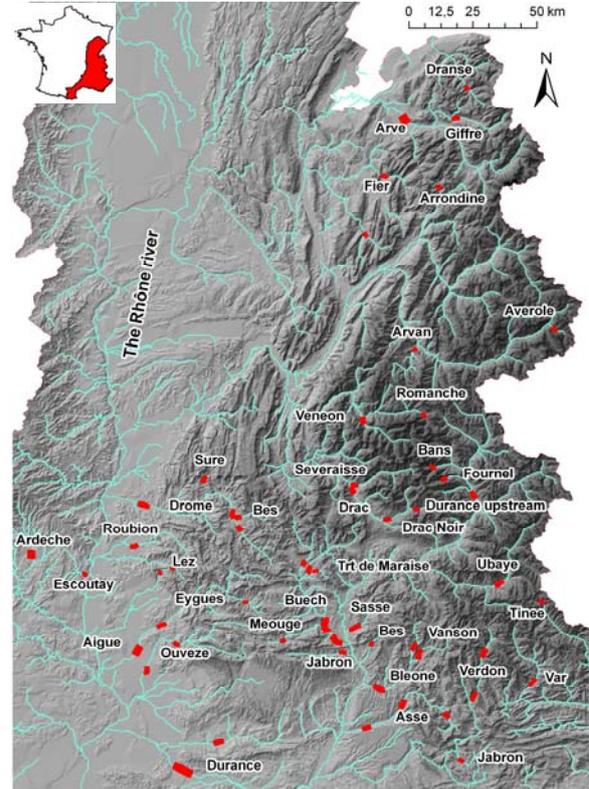


Figure 1. Localization of the 50 studied braided reaches in the Rhône hydrographical network.

3.2 Method

In this study the interest is to test the application of the object-oriented method on several sites, and its automation at a regional scale. The application of the method on many sites presents some problems; the most important obstacle is the difference in spectral values between images, then the spatial variability between sites and finally the structural complexity of braided rivers. These characteristics make the treatment of images, the objects' extraction and the comparison between sites difficult.

Therefore we have been obliged to treat aerial photos by histograms stretching to reduce spectral variability between them and to permit the comparison between sites.

In the *segmentation* process we used the "multiresolution segmentation" algorithm (Barbier, 2006) on eCognition Definiens® which works with the combination of three parameters: scale, shape, and compactness. The selection of parameters value depends primarily on the objective of the study. Here, visual tests have been made to select the best combination between the three parameters, focusing primarily on water polygons because of the interest of river channel network extraction.

Two *classification* methods are permitted in eCognition (Perez Correa, 2004): an “expert” classification, in which it is the operator who introduces discriminating functions (based for example on spectral, textural and homogeneity parameters) and a “supervised” one where the software selects functions on the basis of given samples of objects for each class. For this study we have chosen an expert classification method based on an initial manual classification (by photo-interpretation) on a sample of images selected in the whole network. This initial manual classification has been used like a model for the classification on the overall data set. Figure 2 shows a scheme of the different phases of the method.

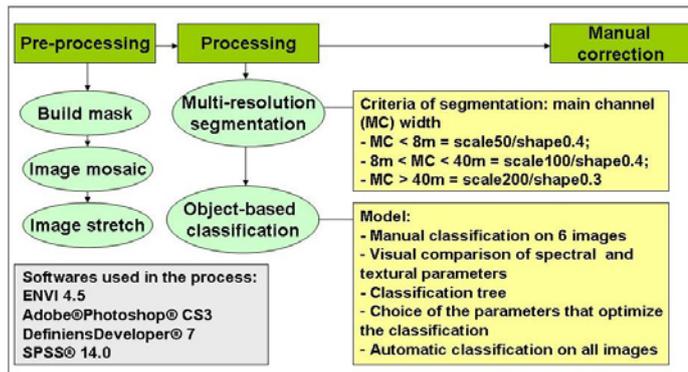


Figure 2. Scheme of image treatment method.

3.3 Results

Concerning the *segmentation* process, the values of scale, shape and compactness have been selected to identify primarily the water channel network. Therefore we have applied different values on the basis of water channel width measured manually (on ArcGis software) on a random selected sample of reaches. Based on our visual test, the parameter which best permits to identify channel network is the scale parameter (Figure 3).

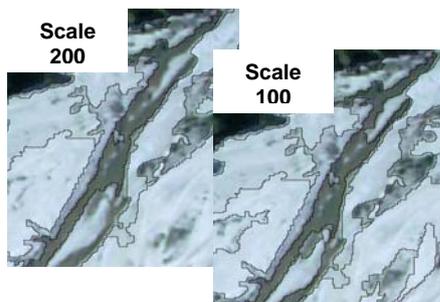


Figure 3. Example of different segmentation results based on scale.

For a channel width less than 8 meters we have chosen a scale value of 50. For a channel width between 8 and 40 meters, we have chosen a value of 100 and for larger channel widths a value of 200. Shape parameter has been set to 0.4 (and so 0.6 for colour) except for channel width larger than 40 meters (shape 0.3, colour 0.7). Compactness has been set to 0.5 for all the images.



Figure 4. Example of river corridor classification: green, mature vegetation; orange, pioneer vegetation; yellow, gravel bars; blue, water.

In the *classification* process we started with a manual classification by photo interpretation on 6 images, chosen in the whole dataset and with different spectral and spatial characteristics. The first step has been the selection of classes: water, gravel bars and vegetation (and shadow); vegetation has been subdivided into grassland, pioneer vegetation and forest (Figure 4).

Following visual comparisons we have selected discriminating functions for the construction of a decision tree. From the decision tree we have then extracted those functions and relatives threshold parameters which optimized the classification (optimized classification tree). 72.3% of objects were then well classified (Table 3).

Table 3. Synthetic results of the optimized classification tree.

| | n. objects per class | n. objects classified per class | % per class | % TOT |
|----------------|----------------------|---------------------------------|-------------|-------|
| FOREST | 1234 | 1148 | 93,03 | 72,32 |
| SHADOW | 166 | 81 | 48,80 | |
| PIONEER SPARSE | 546 | 311 | 56,96 | |
| GRASSLAND | 130 | 54 | 41,54 | |
| GRAVEL BAR | 1283 | 1038 | 80,90 | |
| WATER | 478 | 143 | 29,92 | |

Then we applied the model to all the images using the tool “hierarchical classification” and classified objects have been corrected manually. Finally we merged objects in larger polygons of the main class with the tool “merge region” and exported them in a shapefile format on ArcGis9.2.

In the table below (Table 4) some extracted metrics are shown; these metrics are then combined and processed to build a synthetic index reliable to geographical parameters like slope, altitude, catchment area, hydrological variable, etc.

Table 4. Example of raw metrics and synthetic index extracted from classified objects and applicable synthetic index.

| | | Objects/polygons class | | | | |
|------------------------|-----------------|------------------------|-------------|----------------------------|-----------|-----------------|
| | | water channels | gravel bars | islands (pioneer - mature) | grassland | riparian forest |
| Metrics | area | X | X | X | X | X |
| | perimeter | X | | X | X | |
| | length | X | | X | | |
| | width | X | | X | | X |
| | number | X | X | X | X | X |
| Synthetic index | index form | | | X | X | |
| | proportion | X | X | X | X | X |
| | diversity index | X | X | X | X | X |
| | amplitude | X | | | | |
| | sinuosity | X | | | | |
| | braiding index | X | | | | |

3.4 Discussion

The classification process has produced a good classification of the overall dataset (72.3%, Table 3); this is possible thanks to the wide range of available classification parameters present on eCognition Definiens. However an important amount of time has been dedicated to the manual correction of the classified objects; a large part of the corrections are linked to the segmentation process results. The causes are the wide spectral variability between images which have been taken at different times and represent a wide geographical area and also the structural complexity of river mosaic at one site.

Here we have demonstrated the applicability of the object-oriented method for the extraction of spatial metrics at a regional scale. However more detailed object extractions are not possible at this wide scale: for example the classification of vegetation has not very been detailed, because of the large spectral variability within images. For this purpose it could be suitable to add infrared images which are now available. The identification of habitats in the network of channels (main channel, secondary channel, alluvial channel, etc. according to the main channel connection) is also not possible, and it has been made manually (Table 5).

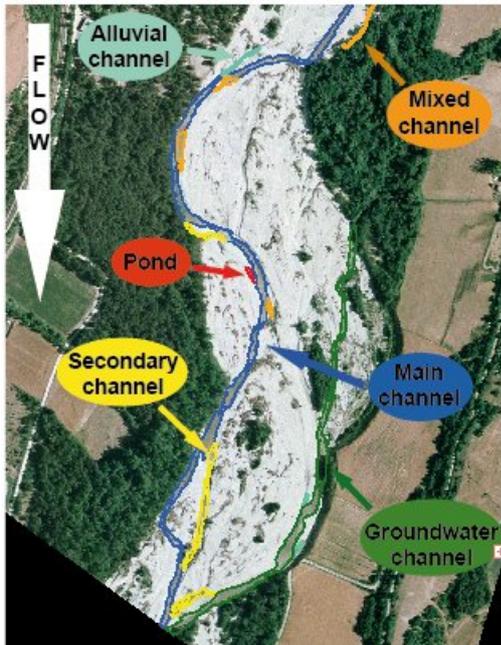


Figure 5. . Aquatic habitats classification.

Table 5. Aquatic habitats classification legend.

| | | |
|-----|---------------------|--|
| MC | Main channel | largest flowing channel |
| SC | Secondary channel | channel upstream/downstream connected with the MC |
| MIX | Mixed channel | channel upstream connected with MC |
| AL | Alluvial channel | channel downstream connected with MC |
| GW | Groundwater channel | channel with alluvial and hillslope contribution (upstream disconnected from MC) |
| P | Pond | channel within the AC area disconnected from the MC |
| T | Tributary channel | affluent |
| WL | Wetland | disconnected wetted area out of the AC area |

Following this procedure, metrics extracted from the polygons obtained by the classification process are then available for

several analyses. For our purpose the analysis of the braided riverscape is made at two different scales: the corridor scale to characterise and identify geographical patterns based on general parameters and including the riparian patches; at the scale of the network of aquatic channels constituting the braiding itself for characterising the pattern of braid and the aquatic habitats diversity.

The corridor characterisation is focused on the active channel area based on the merging of water channels and gravel bars, or on the total channel area (the area included between side-banks, which concern active channel but also every mid-channel islands or cluster of vegetation (Toone, 2009)). Following this procedure, it is then possible to explore extracted geometrical metrics and their interactions to highlight general geographical controls: as shown on the figure 6, an example of the relation between the active channel width and the catchment area.

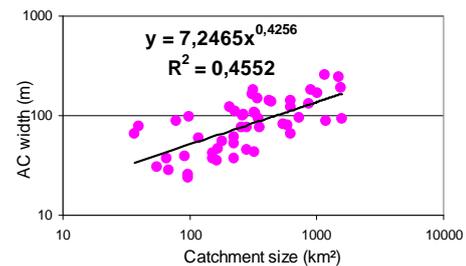


Figure 6. Statistical relationship between the active channel (merge of water channels and gravel bars) width and the catchment area.

For the characterization of the network of aquatic channels, different questions are considered, linking the geometrical metrics with the discharge but also with other parameters characterizing the morphology of the braided reach. Starting from channel length, it is possible to calculate for example the sinuosity index or the braiding intensity, to explore river pattern in relation to hydrological conditions.

4. LONGITUDINAL VARIATION OF MESO HABITAT CONDITIONS THROUGH A SINGLE REACH

In this part, we present a method in order to identify the longitudinal variation of meso habitat from radiometric values of orthophotographies.

4.1 The Drôme River.

To implement the method, we made a series of tests on the main channel of the Drôme River. The Drôme River is 106 km long. This basin has an area of 1640 km² (Figure 6). It is characterized by very contrasted landscapes, including many areas of braided reaches. Management issues of this basin are related to conservation of alluvial forests and restoration of fish habitats.

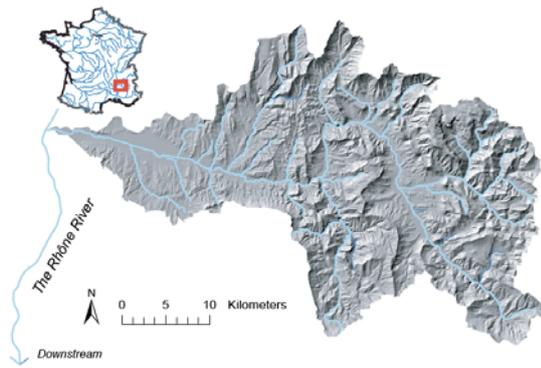


Figure 6. Presentation of Drôme River watershed (Alber, *in press*).

4.2 Method - Extraction of spatial units.

The aim here is to extract homogeneous and continuous metrics along a hydrographic network or at least a river continuum, of many hundred or thousand km long. To extract these metrics we created two types of spatial units (Figure 7): segmentation polygons and Disaggregated Geographic Object (DGO).



Figure 7. Examples of segmentation polygons (in black) and disaggregated Geographic Object (in red).

Previously, we extracted three classes of polygons by oriented-object classification: water, gravel bars and vegetation similarly to what has been shown before. Then, we used polygons of water, which we call the channel.

The segmentation polygons in channel are built using the extraction module of the software Envi Zoom. We used the part segmentation software of the feature extraction. In this software, the segmentation is in 3 steps. The first step is to adjust the level of scale to delineate the boundaries and the size of objects. The second step is the level of merging objects. The last step is the refinement of the segmentation. It is the aggregation of adjacent objects with similar brightness. To choose the threshold of three parameters, we did a set of tests. Then we selected the thresholds visually.

To build the DGO, we segmented the channel by spatial units every 10 m.

4.3 Results : mesohabitat identification

To detect aquatic habitats, we identified the different aquatic patches (semi-) automatically from radiometric values of the orthophotographies, and performed a discriminant analysis.

4.3.1 Dataset tested. We performed tests on the downstream of the Drôme River, on about 50 km. We identified 530 segmentation polygons. For each polygon, we determined its geomorphic nature: riffle, pool, lentic / lotic channel, gravel bench. We recognized also the shaded areas.

We then extracted for each polygon 15 radiometrics values using the “statistical zonal” tools of the ArcGIS software: for

each channel (red, green, blue), we extracted median, mean, standard deviation, minority and majority. We also characterized polygons with morphometrics using ET Geowizards tools. These metrics are the length and the width of polygon.

4.3.2 Discriminant analysis. We then separated the set of data in two groups. The first part was used to establish a discriminant model. The second part was used to validate the model. The model has been put in place using the discriminant analysis.

The graph of discriminant analysis shows that pools and shadows are well differentiated. However the riffles are not well identified partly mixed with lentic/lotic channel and gravel bench (Figure 8).

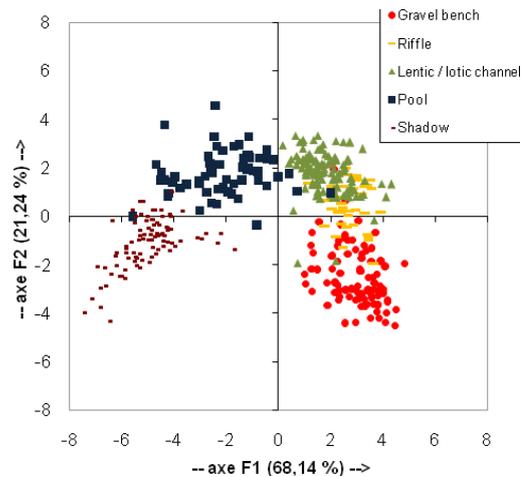


Figure 8. Discriminant analysis

4.3.3 Validation model. Following the cross-validation procedure, we compared the results between the predicted and observed data. The observed data correspond to data determined by photointerpretation whereas the predicted data are the ones calculated by the statistical model. The low results concern the detection of riffle and lentic / lotic channel. But 90% of polygons are classified correctly (Figure 9).

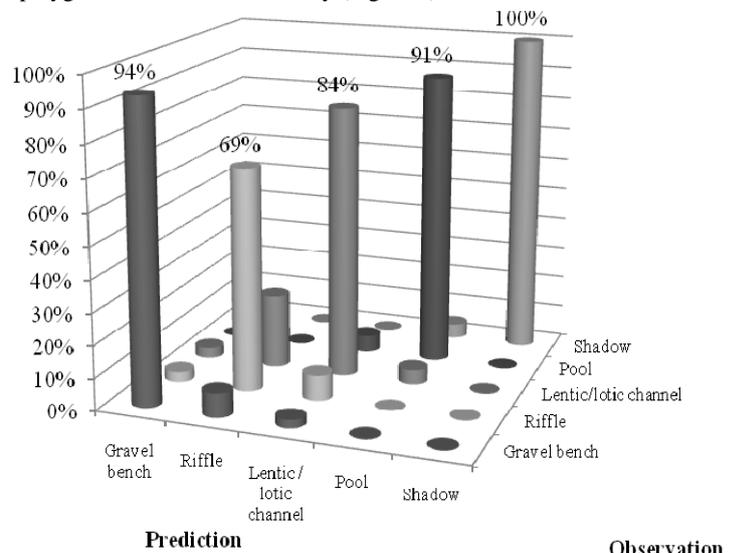


Figure 9. Results of the cross-validation procedure using the independent data set.

4.4 Discussion

4.4.1 Evaluation of ecological state. The fish diversity is considered as an indicator of the ecological state following the Water Framework Directive. It is therefore important to understand its level and design actions notably at the habitat scale to improve it if necessary. In this context, it is meaningful to identify and characterise the variety of fish habitat.

We developed two approaches to study these habitats:

- Firstly, we compared the longitudinal evolution of mesohabitat conditions in observing the upstream / downstream pattern of the metrics characterizing it. For example, we can map the density of pools by geomorphological homogeneous reaches (Figure 10). We calculated this metric by dividing the number of pools by the length of reaches.

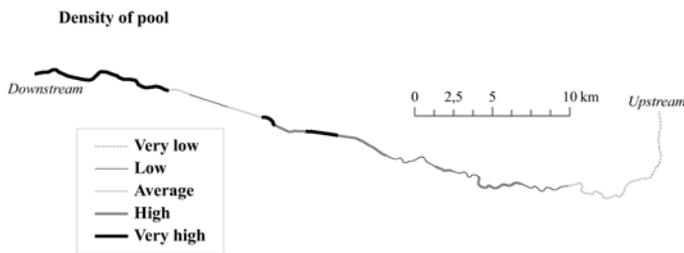


Figure 10. Density of pool by geomorphological homogeneous reaches

- Secondly, we compared the meso-habitat conditions within each of the geomorphic reaches considering the habitat pattern should be for example different from an embanked narrow reach to a wide braided reach. In calculating the surface of habitats, we could obtain the repartition of each habitat in function of fluvial pattern (Figure 11).

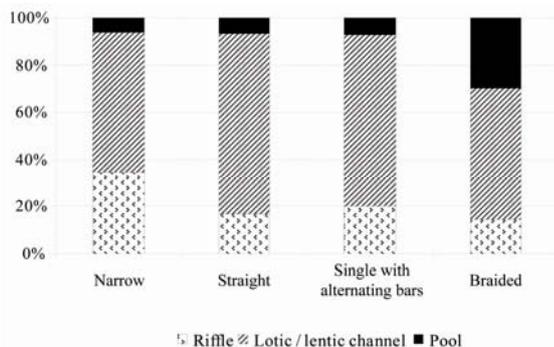


Figure 11. Repartition of mesohabitat by fluvial pattern types.

4.4.2 Limits of this method. The limits are linked essentially to the spatial or spectral resolution of image. There are several reasons:

- in upstream reaches, the channel can be too narrow,
- the vegetation can cover the channel,
- the shadow does not permit to differentiate channel from shadow.

However this method can be used to work at large scale, for example at the Rhone hydrographic network scale. Besides, as the data is stored we can use the extracted metrics to answer other scientific questions, such as the detection of geomorphosites.

5. CONCLUSION

Here we have presented only a few examples of metrics that could be extracted from an objects-oriented method and their application. Several metrics could be extracted from remote sensing of rivers images both for longitudinal characterization of aquatic habitats and for inter-sites riverscape comparison at network scale.

The analysis of river landscape will be extended to the overall river corridor including river banks vegetation; temporal changes in river dynamic considering several dates of aerial images will be included in the analysis too. Moreover results from the longitudinal characterization of aquatic habitats will drive this kind of analysis on inter-site comparison. These results could be useful to better understand the functioning of rivers system; results could also be useful to link geomorphological to biological processes to achieve the objectives of the WFD.

The metrics of fish habitat can be used for scientific studies which raise issues on the space-time variability of fish habitats at a regional network scale. Such tools shall also be useful for managers to assess and monitor habitat quality to the implementation of the WFD.

Results from remote sensing on freshwater environments are also useful both to support decision maker in water management and to provide understanding of the dynamic mechanisms of river.

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