APPLICATION OF PHOTOGRAMMETRY IN FRESHWATER ECOLOGY: ANALYSING THE MORPHOLOGY OF A HIGH ALPINE FLOOD-PLAIN

Rainer ZAH*, Markus NIEDERÖST and Urs UEHLINGER***

*Swiss Federal Institute for Environmental Science and Technology (EAWAG),
8600 Duebendorf, Switzerland
Departement of Limnology and Hydrobiology
zah@eawag.ch
**ETH Zürich, Switzerland
Institute of Geodesy and Photogrammetry
markus@geod.baug.ethz.ch

Working Group VII/2

KEY WORDS: Digital elevation model, Orthophoto, Infrared, Ecosystems, Running water, Flood-plain, Alpine.

ABSTRACT

The shape and structure of river channels (channel morphology) are important features of freshwater habitats. However, determination of parameters characterizing the morphology of rivers and flood-plains with classical methods is very time consuming and sometimes even impossible. The application of digital photogrammetry reduces the time for data acquisition and allows analysis of complex and remote flood-plains: Aerial photographs capture a distinct flow situation, which can be analysed later in the laboratory with high accuracy and without time constraints.

In this project, a digital elevation model (DEM) and color-infrared orthophotos were generated at a resolution (DEM: 2 m, Orthophoto: 0.25 m) that allowed the measurement of different morphological parameters of channels in the Val Roseg flood-plain (eastern Swiss Alps). Based on these photogrammetric data, channel area, channel length, mean channel width, channel slope, bank inclination, and riparian vegetation density were successfully calculated. The assessment of variability in width and slope of channel segments however was affected by the highly complex floodplain structure and the limited DEM resolution.

Multivariate analysis showed, that the morphological parameters clustered the channel segments into different channel types, thus indicating the high ecological relevance of the results.

1 INTRODUCTION

Knowledge of the physical aspects of streams, in particular geomorphology and hydrology, are important for understanding the functioning of river ecosystems (e.g. Fisher et al., 1998). Geomorphic settings, such as channel size, slope, grain size distribution, the spatial configuration of bars and riparian vegetation strongly influence the structure of fluvial habitats and, as a consequence, biodiversity and ecosystem function. Physical characteristics of rivers can be studied at spatial scales that range from sediment grains of 10^{-3}m to drainage systems of >10^{3} km (Frissell et al., 1986), but stream ecology traditionally has focused on channel processes (Fisher, 1997). This focus determined the scale of observation typically ranging from microhabitat to reach. However, by adopting a landscape perspective, stream ecologists are expanding the scale of their investigations (Johnson and Gage, 1997; Richards et al., 1997; Ward et al., 1999).

At the reach scale, relevant morphological parameters such as channel width, slopes of channels and banks, and riparian vegetation are usually assessed using simple tools such as meter tapes, inclinometers and vegetation classification techniques. These techniques yield reliable data but become painstaking if the interest is expanded to the channel network of an entire drainage. At this scale, modern photogrammetric methods such as ortho-photographs and digital elevation models (DEMs) in high resolution make it possible to extract morphological parameters, that are of ecological significance for stream habitats. Such parameters include (1) channel length, channel slope, stream area, and mean channel width that define the spatial extent of the aquatic ecosystem, (2) variability in channel width and slope as indicators of habitat diversity, and (3) the inclination of the adjacent riparian zone and riparian vegetation density that are correlated with the input of terrestrial organic matter to aquatic systems (Figure 1).

The objective of this study was to demonstrate the benefits and limitations of photogrammetry and geographical information systems (GIS) for the assessment of ecologically relevant geomorphic parameters at the floodplain scale. The project was conducted in a high alpine flood-plain (Val Roseg, eastern Swiss Alps).

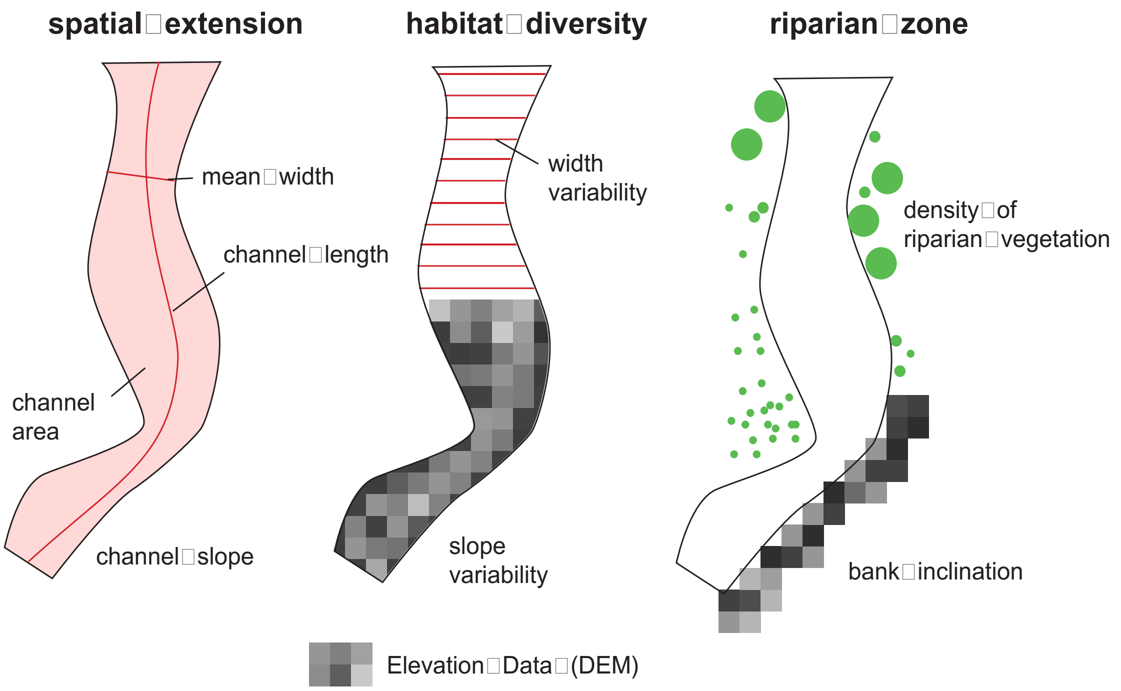

Fig. 1. Schematic view of morphological characteristics of a stream segment.

2 METHODS

2.1 Study system

The study system was the Roseg River in the eastern part of the Swiss Alps. About 30% of the drainage basin (area 66.5 km^2) is covered by glaciers. Meltwater from the Tschierva and Roseg glaciers is the primary water source of the Roseg River. The most remarkable feature of this system is a glacial flood-plain (length 2800 m, about 2100 m a.s.l.) comprising a diversity of channel types. Within this flood-plain, the following channel types can be distinguished based on their hydrological connectivity and physico-chemical attributes (modified from Tockner et al., 1997): (1) main channel primarily draining the flood-plain that is mainly fed by glacial meltwater of the Tschierva and Roseg glaciers, (2) side channels with upstream and downstream connections to the main channel, (3) intermittently-connected channels permanently connected downstream and intermittently connected upstream to the main channel, (4) groundwater channels fed by alluvial groundwater and only connected downstream with the main channel, (5) groundwater channels fed by lateral groundwater exfiltrating from the edge of the flood-plain and only connected downstream with the main channel, (6) tributaries entering the flood-plain from side-valleys and fed by hillslope aquifers or small side glaciers.

2.2 Geodetic methods

Aerial photographs (color film and color infrared film) of the Val Roseg flood-plain were taken on 29 July 1998, at 13:00 GMT with a standard aerial camera (WILD 21 NAGIIA-F, focal length 214.74 mm). At this time of the year most floodplain channels have surface flow and the shrub and grass vegetation is well-developed. Coordinates of the signalized control points were determined with GPS before the flight.

Color film was used for the generation of digital elevation models, while orthophotos were created from color infrared images for a better differentiation of vegetation patterns and wet areas (Fig. 2a). Both kinds of film were used on two different flight heights. Two high image strips (scale 1:9‘500, scan resolution 21 microns) covered the entire valley (flood-plain and side-slopes). Two low elevation image strips (scale 1:5‘000, scan resolution 21 microns) provided high resolution and accuracy for the floodplain area. The exterior orientation of the images was determined in a bundle block adjustment for each strip separately.

The photogrammetric evaluation was completed with the digital station PHODIS (by ZI-Imaging). The data provided for the analysis with GIS consisted of a DEM with a rasterwidth of 2 m for the flood-plain (estimated height accuracy about 0.12 m) and a DEM with a rasterwidth of 10 m for the adjacent valley slopes (estimated height accuracy about 0.25 m). Digital color infrared orthophotos of the floodplain were created with a footprint of 0.25 m. Although the spatial resolution is limited by the raster-width of the DEM, the higher resolution of the orthophotos ensures that small objects (0.25 - 2.0 m) are preserved and can be analyzed. Orthophotos of the adjacent valley slopes were created with a resolution of 0.5 m, which is sufficient for the assessment of vegetation patterns. Three separate color bands were extracted from the infrared orthophotos to separate six classes of vegetation density (bare gravel, sparse grassland, intermediate grassland, dense grassland, grassland with shrubs, and forest) by applying maximum-likelihood classification.

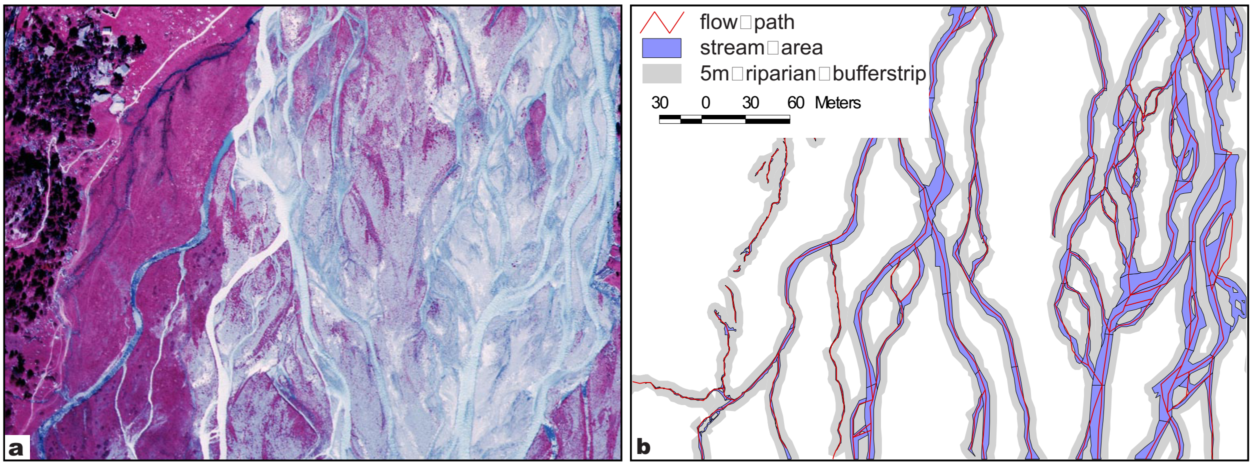

Fig. 2. a: Part of a high-resolution color-IR-orthophoto, b: digitized coverages for the same area indicating flow paths, stream segments and the riparian bufferstrip.

2.3 GIS analysis

Photogrammetric data were analyzed with ArcInfo (by ESRI): Coverages were digitized with ArcEdit and raster data were generated and analyzed with ArcGrid. First, a line coverage was created representing the main flow paths of the different channels. Next the channel area of the whole flood-plain was digitized as polygons (Fig. 2b). Both, flow path and channel area coverages, were split into about 500 segments with a maximum length of 150 m per segment. For each channel segment, all morphological parameters were calculated using combinations of the four coverages: flow paths, channel area, vegetation density, and DEM (Fig. 1).

First, each segment was assigned to one of five <u>channel types</u> (main channel, intermittently-connected channel, groundwater channel, lateral groundwater channel, or tributary). As the next step, <u>channel area</u> and <u>channel length</u> per segment were derived from the ArcInfo coverages. <u>Mean channel width</u> was calculated by dividing the area of each channel segment by the channel length of the respective segment. <u>Variability in channel width</u> was determined by intersecting the channel area coverage with parallel lines transecting the flood-plain every 2 m. The resulting coverage included replicated channel width measurements that were linked to the respective channel segments. Width variability was calculated as the standard deviation of all width measurements of one channel segment. Direct and indirect methods were used to determine channel slope. In the indirect method, the slope in each raster point of the DEM was calculated as the change in altitude of the neighboring cells (Slope-function of ArcGrid). Next, a point coverage was generated including sampling points every two meters of the thalweg coverage. With this point coverage, slope was measured for all segments every two meters on the main flow path. Finally, <u>mean channel slope</u> and <u>standard deviation in slope</u> were calculated for each channel segment. With the direct method, mean slope was calculated directly from the DEM: (max. altitude – min. altitude) / channel length * 100. However, this method only yields the mean slope, the determination of slope variability is not possible with the direct method. A 5m-wide, lateral strip along each channel segment was analyzed to generate morphological parameters of the riparian zone. Within this strip, <u>mean vegetation density</u> and <u>bank inclination</u> of the riparian zone were determined using the zonal functions of ArcGrid.

The resulting morphological parameters were visualized on a floodplain map using ArcView 3.1 (by ESRI). To separate channel types, principle component analysis (PCA) was performed using ADE 4-Software (Chessel and Dolédec, 1996).

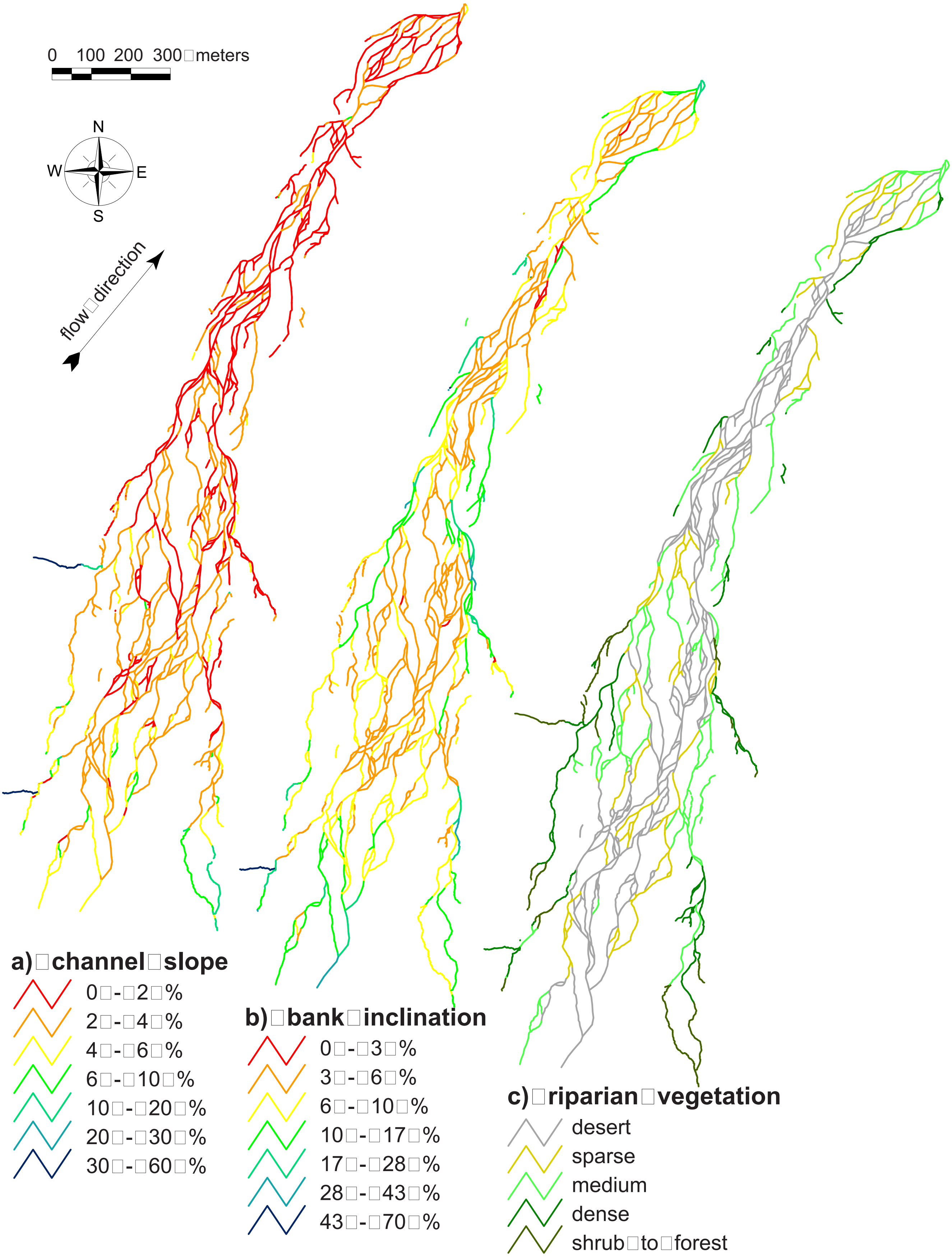

Fig. 3. Visualization of selected morphological parameters on the channel network of Val Roseg.

3 RESULTS AND DISCUSSION

3.1 Channel characteristics

Segments of the main channel and of intermittently-connected channels contributed 70% and 20% to the channel area of the entire flood-plain (Table 1); this means that 90% of the channels in the floodplain are directly fed by glacial melt water during summer. The mean width averaged 5.1 m for main channel segments and 3.3 m for intermittently connected channels. Channel types lacking upstream connections to the main channel were on the average ≤ 2 m wide and also showed a lower variability in channel width (Table 1).

Channeltype	Number of segments	Total stream area	Total channel length	Mean channel width	Channel slope (direct method)	Bank inclination	Riparian vegetation density
		m^2	m	m	%	%	1:bare, 6:forest
main channel	169	69432	12992	5.1 ± 2.2	2.4 ± 1.2	7.3 ± 5.2	1.2 ± 0.4
intermittently-connected channel	114	26246	7805	3.3 ± 2.5	2.6 ± 1.3	6.0 ± 2.5	1.4 ± 0.4
alluvial groundwater channel	40	3204	1702	1.6 ± 1.2	3.4 ± 2.9	9.1 ± 4.7	2.4 ± 0.8
lateral groundwater channel	72	5523	2135	2.1 ± 1.6	2.3 ± 1.5	10.1 ± 7.0	2.8 ± 1.0
tributary	93	5734	3346	1.5 ± 1.7	5.5 ± 6.1	16.2 ± 13.8	3.2 ± 1.0

Table 1. Morphological values for the different channel types (mean ± 1 SD).

Channel slope was over-estimated by the indirect method, particularly in narrow channels with steep banks where the inclination of the riparian strip strongly affected estimates of slope. Therefore, these results were not considered for further analysis. Interference with the riparian strip was small with the direct method, and thus results are more representative for channel slope. Mean slopes of main channel segments, intermittently-connected channel segments, and lateral groundwater channels segments were about 2.5%, while mean slope of alluvial groundwater channels was 3.4% and slope of tributaries averaged 5.5%. The channel types with steeper slopes also showed higher variability in slope (Table 1). Slopes of channel segments were remarkably uniform in the middle of the floodplain, while slopes slightly increased towards the upper part and edges of the flood-plain (Figure 3a).

Because of high connectivity between the main channel segments (braided channel pattern, shown in Fig. 2a), we failed to determine channel width every two meters and, as a consequence, variability of channel width within channel segments. However, variability in width among channel segments was high for intermittently-connected channels and for the main channel segments, and lower for the other stream types with narrow channels. Channel width was inversely related to channel slope (Fig. 4b).

3.2 Characteristics of the riparian zone

The lowest bank inclination was found for intermittently-connected channel segments (6.0%). This channel type also showed the lowest variability among segments. Mean bank inclination for the main channel was 7.3% with a standard deviation of 5.2%. The standard deviation is so high because the main channel was partially eroding the steep valley slopes. Mean bank inclination for alluvial and lateral groundwater channels was 9.1% and 10.1% (Table 1). Inclination of the riparian bank was maximum for tributary segments. Inclination was generally higher along the edge of the floodplain than in the middle of the flood-plain (Fig. 3b). Highest values have been found in the uppermost part of the flood-plain where the main channel incised glacial deposits.

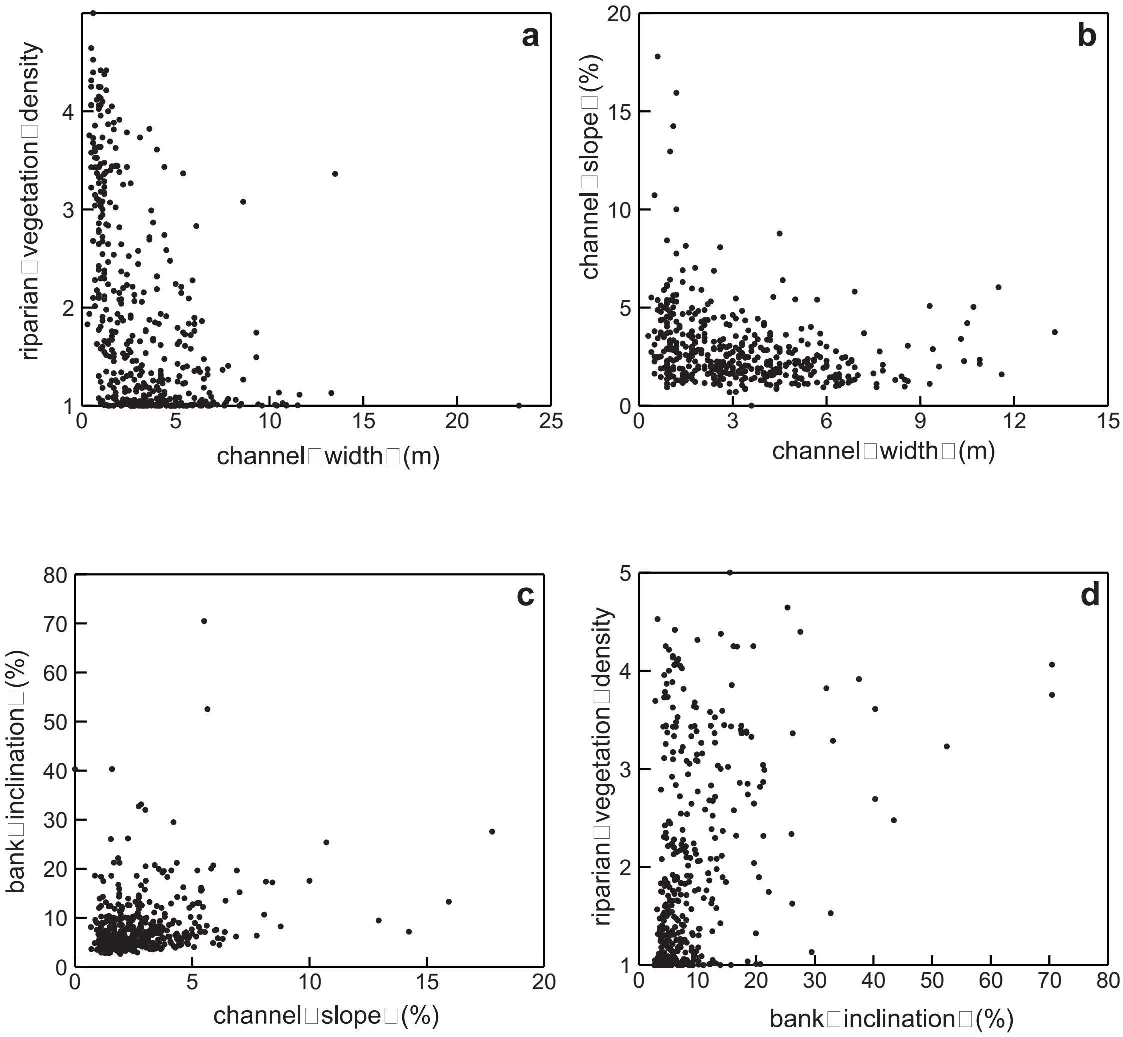

Fig. 4. Relationships between selected morphological parameters. Dots represent values of single channel segments.

Riparian vegetation density along main channel segments was scarce or lacking (Table 1, Fig. 3c), apparently reflecting low channel stability during high flows and high sediment supply from recent proglacial areas. Vegetation along intermittently-connected channels was nearly as low (Table 1). Riparian vegetation density of groundwater channels in the middle of the flood-plain was relatively high indicating that these channels are restricted to stable parts of the flood-plain. The highest vegetation density was found along tributaries and groundwater channels at the floodplain edge. Density of the riparian vegetation significantly decreased with channel width (Fig, 4a). However, figure 3c shows that some stable spots with dense vegetation existed even in the middle of the flood-plain. Our data generally show that restricted channel movement coincided with steep bank slopes. This is reflected by a positive relationship between bank inclination and vegetation density (Fig. 4d), both of which are important determinants of the input of allochthonous organic matter in floodplain channels (R. Zah, unpublished data).

3.3 Channel typology

In order to cluster the channel types using the morphological parameters, a multivariate analysis (PCA) was performed (Fig. 5). Channel types were mainly separated by the primary axis which explained 55% of the variation. The primary axis was positively correlated with channel width and negatively correlated with vegetation density and channel slope (Fig. 5b). The different channel types were aligned along this gradient; main channels and intermittently-connected channels are clustered together on one end of the gradient, followed by alluvial and lateral groundwater channels in the middle, and the tributaries on the other end of the gradient (Fig. 5a).

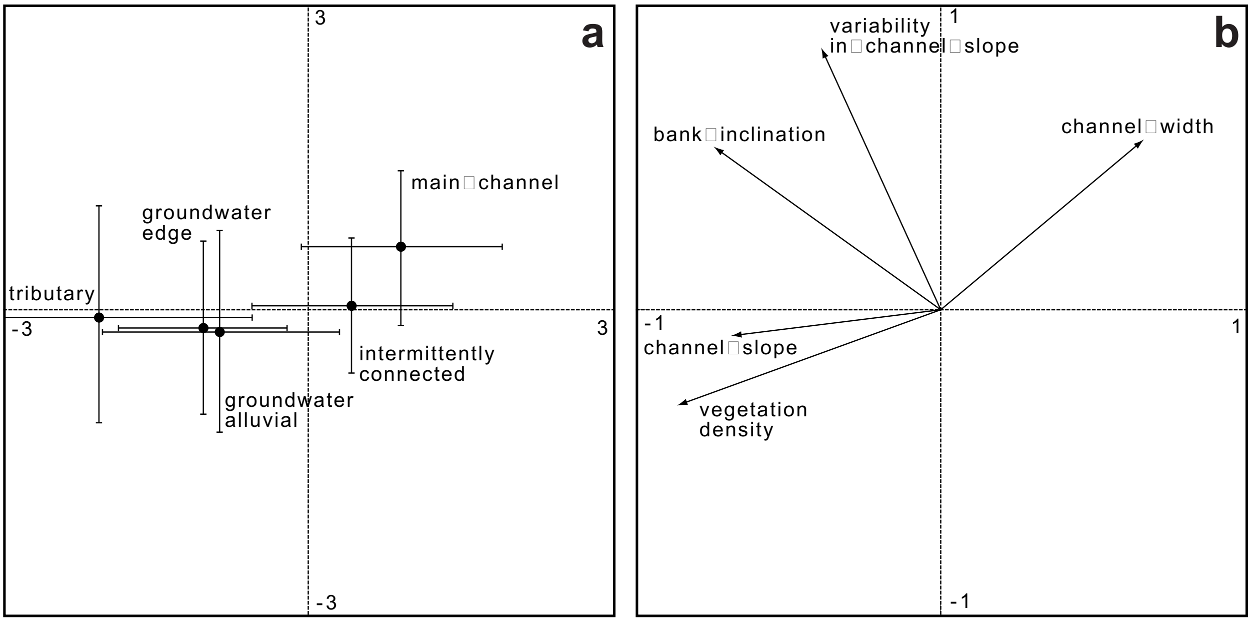

Fig. 5. Primary component analyis (PCA) based on all morphological parameters: a) values for the channel segments of each channel type (mean ± 1 SD), b) values for the morphological parameters.

4 CONCLUSION

By using digital photogrammetry it was possible to calculate a high-resolution DEM and to generate ortho-photographs of a much higher accuracy than by applying a simple rectification with tie points. The photogrammetric method yielded all data necessary for deriving morphological parameters at the scale of the Val Roseg flood-plain. However, the spatial resolution of the DEM (2 m footprint) imposed some constraints on the calculation of channel slope. In narrow channels (width < 5 m) with steep banks, channel slope was over-estimated, because the slope function in ArcGrid could not satisfactorily separate channel slope from bank slope. Therefore, the correct DEM resolution for slope calculations should be taken into account early in planning of future projects.

GIS analysis provided data that are considered to determine biotic pattern and processes in stream ecosystems, but that would have been rather difficult to obtain with standard methods with regard to the size and complexity of the investigated system. Another advantage of the methods applied in this project is the high spatial resolution of the data which makes it possible to use statistical methods from landscape ecology and geostatistics for further analysis.

This project showed that standard methods of digital photogrammetry have a high potential to influence scientific progress in other disciplines. The contemporary trend in freshwater ecology towards a landscape approach can benefit from a strong interdisciplinary collaboration with photogrammetry.

ACKNOWLEDGEMENTS

We express our thanks to Plinio Testa and his crew at the Hotel Roseggletscher for their hospitality, to the Koordinationsstelle für Luftaufnahmen (KSL) for shooting the aerial photographs, to Peter Burgherr for perform multivariate statistics, and to Chris Robinson for the critical review of this paper. This work was supported by National Science Foundation (SNF grant 21-49243.96).

REFERENCES

Chessel, D. and Dolédec, S., 1996. ADE Version 4: Hypercard Stacks & QuickBasic Microsoft Programme library for the analysis of environmental data. User’s manual. ESA CNRS 5023, Ecologie des Eaux Douces et des Grands Fleuves, Université Lyon 1, France.

Fisher, S.G., 1997. Creativity, idea generation, and the functional morphology of streams. Journal of the North American Benthological Society, 16(2): 305-318.

Fisher, S.G., Grimm, N.B., Marti, E., Holmes, R.M. and Jones, J.B., 1998. Material spiraling in stream corridors: A telescoping ecosystem model. Ecosystems, 1(1): 19-34.

Frissell, C.A., Liss, W.J., Warren, C.E. and Hurley, M.D., 1986. A Hierarchical Framework for Stream Habitat Classification: Viewing Streams in a Watershed Context. Environmental Management, 10(2): 199-214.

Johnson, L.B. and Gage, S.H., 1997. Landscape approaches to the analysis of aquatic ecosystems. Freshwater Biology, 37: 113-132.

Richards, C., Haro, R.J., Johnson, L.B. and Host, G.E., 1997. Catchment and reach-scale properties as indicators of macroinvertebrate species trails. Freshwater Biology, 37: 219-230.

Tockner, K. et al., 1997. Physico-chemical characterization of channel types in a glacial ecosystem (Val Roseg, Switzerland). Arch. Hydrobiol., 140(4): 433-463.

Ward, J.V. et al., 1999. A reference river for the Alps: the Fiume Tagliamento. Regulated Rivers, 15: 63-75.