Floodplain forest dynamics in a hydrologically altered mountain river

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Abstract: Changes in streamflow and floodplain vegetation of the Maggia River, one of the last remaining natural alluvial rivers with a riparian floodplain forest in Switzerland, are documented. Mean daily streamflow records for the period 1929-2003 are used to illustrate changes in the streamflow regime due to hydropower regulation. Regulation has led to a 75% drop in the average annual streamflow and to the elimination of the summer snowmelt flood. Most affected are moderate flows in the summer rather than flood peaks. Analyses of riparian vegetation cover from six aerial photograph scans in the post-dam period between 1962 and 2001 show the active morphological and vegetation response of the alluvial zone in a 600 m long study reach. There is a general recent tendency towards a loss in the natural vegetation dynamics, an increase in the riparian forest cover, accompanied by a decrease in exposed sediment and grass/shrub covers. The importance of the magnitude and frequency of summer high flows for the rejuvenation of the riparian zone and vegetation colonization are highlighted. It is also illustrated that widely spaced snapshots of vegetation cover from aerial photography are not sufficient to understand the short-term variability in riparian vegetation dynamics.

1. Introduction

Understanding the natural dynamics of patterns and processes in floodplains and the connection between the flow regime, river morphology and riparian vegetation have fundamental practical consequences for effective river restoration and water management (e.g., Poff et al., 1997; Ward et al., 2001; van der Nat, 2003). In Europe, widespread river training and flow regulation has led to the gradual disappearance of most floodplain forests (e.g., Tockner & Stanford, 2002). Water extraction for hydropower purposes has changed the natural streamflow regime of many rivers, in particular in Alpine mountain basins. Yet it often remains unclear how streamflow changes may have impacted riparian ecosystems in these basins, in particular the last remaining floodplain forests, in the long term. The analysis of observed flow and vegetation dynamics is a necessary first step in an assessment of these impacts. Here we document some observed changes in the natural flow regime and in the floodplain vegetation distribution of a section of the Maggia River, which is one of the few remaining natural alluvial rivers with a braided gravel bed stream and riparian floodplain forest in Switzerland.

Changes in the streamflow regime in the Maggia River are the result of the construction and operation of a complex hydropower system in the headwaters of the basin since 1954 (see Ruf et al., 2005, this issue). The changes we highlight here are not only a general decrease in flow due to water extraction, but more importantly a significant change in the seasonality of flow and its distribution. These hydrological alterations have led to a general drop in groundwater levels and to substantial changes in the timing and magnitude of floodplain inundation in the affected section of the river. Under natural conditions, riparian succession towards terrestrialization is countered by episodic rejuvenation due to scouring floods and channel migration (e.g., Resh et al., 1988; Ward et al., 2001). Therefore changes in the timing and magnitude of flooding and in the predictability of flow seasonality are likely to strongly impact riparian vegetation dynamics and floodplain biodiversity in general (e.g., Ward et al., 1999). Furthermore, surface water and groundwater exchange in the Maggia River is proving to be an important factor in the water dynamics (Ruf et al., 2005, this issue), and observations have shown that riparian tree species are sensitive to water table decline (e.g., Amlin & Rood, 2002).

There is evidence that riparian vegetation in the Maggia floodplain has responded to streamflow and groundwater changes, in particular a sensitivity to flood disturbance was observed (Bayard & Schweingruber, 1991). Preliminary investigations of aerial photographs from a short (about 600 m) geomorphologically active study reach reported here also show that the type and extent of vegetation cover has changed quite substantially in the post-dam period between 1962 and 2001. There appears to be a tendency towards a loss in the natural dynamics and a gradual maturing and stabilization of the floodplain forest under regulated flow. Future investigations of a longer reach of the river and a longer time period, are underway to confirm whether this trend is consistent, to understand the scales of variability involved, and to set up a modelling framework for the analysis of the vegetation dynamics under water stress.

2. Data

The braided reach of the Maggia River between Giumaglio and Riveo is of primary interest here (Figure 1; for general location of basin refer to Ruf et al., 2005, this issue). Apart from the road embankment, the river is not trained in this reach and develops a braided morphology on a floodplain which is approximately 300 to 700 metres wide. The river bed consists of well sorted gravel and cobble grains. The stream banks are exposed or covered with shrubs and grass, the dominant soft-wood species in the floodplain forest are *Alnus incana* (grey alder), *Salix elaegnos* and *Salix purpurea* (Bayard and Schweingruber, 1991).

Mean daily streamflow records were used in this analysis to reconstruct the inflows into the study reach from 1929 to 2003 at the Bignasco gauging station downstream of the confluence of the Bavona and Maggia Rivers. We did not include flow from the ungauged Rovana, a tributary to the Maggia just upstream of the study reach because its contribution is small relative to the flow from upstream. Annual Q and monthly Q_m totals were computed from the daily streamflow data. We also analysed changes in peak discharge Q_p, that is the maximum daily streamflow on annual and monthly bases, and changes in the annual and seasonal distributions of daily streamflow. It should be noted that for large flood events, mean daily streamflow is generally lower than the actual peak flow. Streamflow data were analysed in three periods: pre-dam period (1929-1953) and two post-dam periods (1954-1974 and 1982-2003).

Riparian vegetation change in the post-dam period was analysed in a 600 m study area close to the community of Someo in the braided section of the Maggia River from 6 series of aerial photographs taken between 1962 and 2001 by Favre (2004). The images were orientated and rectified with a 25-m digital terrain model and classified into six main alluvial units (water, sediment, herbaceous areas, riparian forest, non-alluvial forest and non-alluvial areas). Total vegetation cover density and ligneous vegetation density were also recorded for every unit. The classification was used to derive transition indexes between the different alluvial units. Also defined was an index of stabilization which is determined by the fraction of the study area in each class which remain unchanged between subsequent scans (Favre, 2004).

3. Results

3.1. Streamflow seasonality

The construction and operation of the hydropower system has led to a drop in average annual streamflow in the Maggia River from 520 (10^6) m^3/yr prior to dam construction to about 130 (10^6) m^3/yr in the recent period. Most importantly, this 75% loss of the water volume is seasonally dependent. The natural hydrological regime shows two seasonal peaks – a snow melt dominated peak in June and a secondary peak in September-October due to autumn Mediterranean cyclonic storms. Flow regulation has practically eliminated the summer flood, for example streamflow has decreased from an average of 109 (10^6) m^3 to 16 (10^6) m^3 in June (Figure 2). This drop in the mean has been accompanied by a decrease in the variability between seasons.

Our analysis shows that the regulation affects predominantly moderate flows. Because the hydropower system consists of many relatively small reservoirs, large floods are not substantially affected. Figure 2 shows that monthly peak streamflows for regulated periods are somewhat smaller on the average than natural flows, but lie within the natural variability. In fact the regulation has led to an absolute as well as relative increase in peak flow variability. On the basis of this analysis it is not possible to conclusively argue that regulation has led to a decrease in flood magnitude.

However, changes in the seasonality of the flow regime have important consequences for riparian vegetation recruitment and establishment (e.g., Mahoney &

Rood, 1998), and may be partly responsible for the observed loss in vegetation dynamics in the valley.

3.2. Riparian vegetation dynamics

The analyzed vegetation data shows that the alluvial zone exhibits large interannual changes in response to floods. For example, the total vegetated (grass, shrubs and trees) fraction of the study area ranged between 60 and 95% within the six years of aerial photographs. Documented changes following a flood showed a substantial increase in pioneer vegetation stages. There appears to be a general tendency in the study area for a loss in the natural dynamics and maturing of the floodplain forest.

For example, Figure 3 shows the changes in vegetation between 1962, 1989 and 2001. It is evident that the former wide distribution of herbaceous areas in 1962 has matured into riparian forest, especially in the southern part of the study area away from the channels. It is also evident that the braided river system is geomorphologically very active, islands disappear and new ones are formed, and the channels shift position. This creates opportunity for recruitment and grass/shrub growth following floods.

However, it has to be noted that the observed vegetation changes may be particular to the morphology of the short study reach. For example scour frequency is dependent on the local floodplain elevation and braided river dynamics which will also influence riparian vegetation patterns (e.g., Poole et al., 2002). We are currently analyzing a longer section of the river to better understand the possible morphological influences on vegetation patterns. In addition, a hydrological-hydraulic modelling system is being developed (Ruf et al., 2005, this issue) to analyse in more detail the variability of flooding dynamics due to different instream regulation policies and the possible impacts of flood disturbance on riparian vegetation.

3.3. Connections between flow and vegetation change

Some basic connections between changes in the streamflow regime and vegetation change can be made from the annual time series in Figure 4.

The most notable hydrological changes are the decrease in annual total flow and the decrease in the frequency of daily flows with $Q > 50$ m^3/s in the summer season after 1953. The frequency of autumn season high flows has not changed substantially. Interestingly, there is a period of unusually large floods between 1964 and 1974 in the post-dam period. We are exploring the reasons for this.

Riparian vegetation change in Figure 4 illustrates the overall dynamics in vegetation cover in the post-dam period. The main signals are a recent increase in the riparian forest cover, accompanied by a decrease in exposed sediment and herbaceous covers. The period since 1990 has seen moderate summer floods and the frequency of high flows in summer in general has been lower than average. This may have led to a poorer recruitment of seedlings, lower flood disturbance, and thereby to a gradual maturing of the riparian forest. This is likely not an irreversible process and a single large flood may rejuvenate the floodplain forest and recover the natural dynamics.

Regarding the differences in vegetation cover between the years in Figure 3 it seems that 1962 and the preceeding year were particularly dry, with relatively low summer and autumn flood peaks and infrequent high flows. This could explain the low fraction of exposed sediment in the study area because of lack of flood scouring. On the other hand, 1989 was also a dry year but it was preceded by a relatively large autumn flood in 1988 and a summer flood in 1987. Furthermore a major flood in 1978 considerably reshaped the river bed. The flood scour of the stream bed led to the large exposed sediment surface visible in the 1989 scan (Figure 3). This surface was gradually colonized by vegetation and by 2001 the area covered by riparian forest rose from 38 to 71%.

A problem we face with analysing intermittent and widely spaced snapshots of vegetation cover is that we cannot properly identify interannual variability properly. The deceivingly gradual change in vegetation cover in Figure 4 will likely seem more irregular if aerial photography were available every year. It is also not possible to identify the intra-annual change in vegetation, especially the seasonal grass cover, which may substantially change depending on the time when the aerial photographs were taken. To address these issues we are currently installing a permanent monitoring station for terrestrial photography in the visible and near-infrared range from which we will derive vegetation density indexes throughout the year, we will identify the beginning and duration of the growing season and the establishment of plants on bars and river banks following floods.

Together with field surveys of the floodplain this data will serve as support for building a process-based stochastic simulation model for the simulation of long-term floodplain vegetation dynamics. This model will be coupled to a hydrologic-hydraulic modelling system (Ruf et al., 2005, this issue), with the goal to evaluate the impact of different regulation scenarios on long-term vegetation behaviour.

4. Conclusions

This paper presents some documented changes in the streamflow regime due to regulation and changes in riparian vegetation cover in a small study area of the braided section of the Maggia River in southern Switzerland. The aim was to illustrate that the dynamics of riparian vegetation growth are fundamentally dependent on the flow and flooding dynamics in the river.

The most substantial hydrological changes are that regulation has led to a 75% drop in the average annual streamflow after the construction of the hydropower system in 1953. The summer snowmelt flood has been practically eliminated and relative variability in flow has increased. Regulation affects predominantly moderate flows, annual summer or autumn peak flows appear not to be substantially affected. However, a decrease in the frequency of daily flows with $Q > 50$ m^3/s in the summer season after 1953 is evident, while the frequency of autumn season high flows shows only minor changes.

Analyses of riparian vegetation change in the post-dam period from aerial photographs in six years between 1962 and 2001 show that the alluvial zone is highly active in terms of morphological as well as vegetation response. Documented changes are a substantial increase in pioneer vegetation stages in flood years due to the recruitment opportunity on new river banks and islands. However, there appears to be a general tendency in the study area in the period since 1990 towards a loss in the natural vegetation dynamics, an increase in the riparian forest cover, accompanied by a decrease in exposed sediment and herbaceous covers. This period has seen moderate summer floods, and the frequency of summer high flows in general has been lower than average.

The connections between changes in the streamflow regime and vegetation point to the importance of summer floods and the frequency of high flows for the rejuvenation of the riparian zone and the rebuilding of sediment banks and islands for vegetation colonization. However, this paper also illustrates that intermittent and widely spaced snapshots of vegetation cover are not sufficient for properly understanding the intra- and inter-annual variability in riparian vegetation dynamics and for making conclusive connections between hydrology and vegetation growth.

The presented research is part of an ongoing project on the Maggia River (MaVal) under which a comprehensive hydrological-hydraulic modelling system is being developed to study the river-aquifer exchange and its impacts on riparian vegetation dynamics (see also Ruf et al., 2005, this issue). More information about research activities under this project can be found at www.maggia.ethz.ch or can be obtained directly from the first author.

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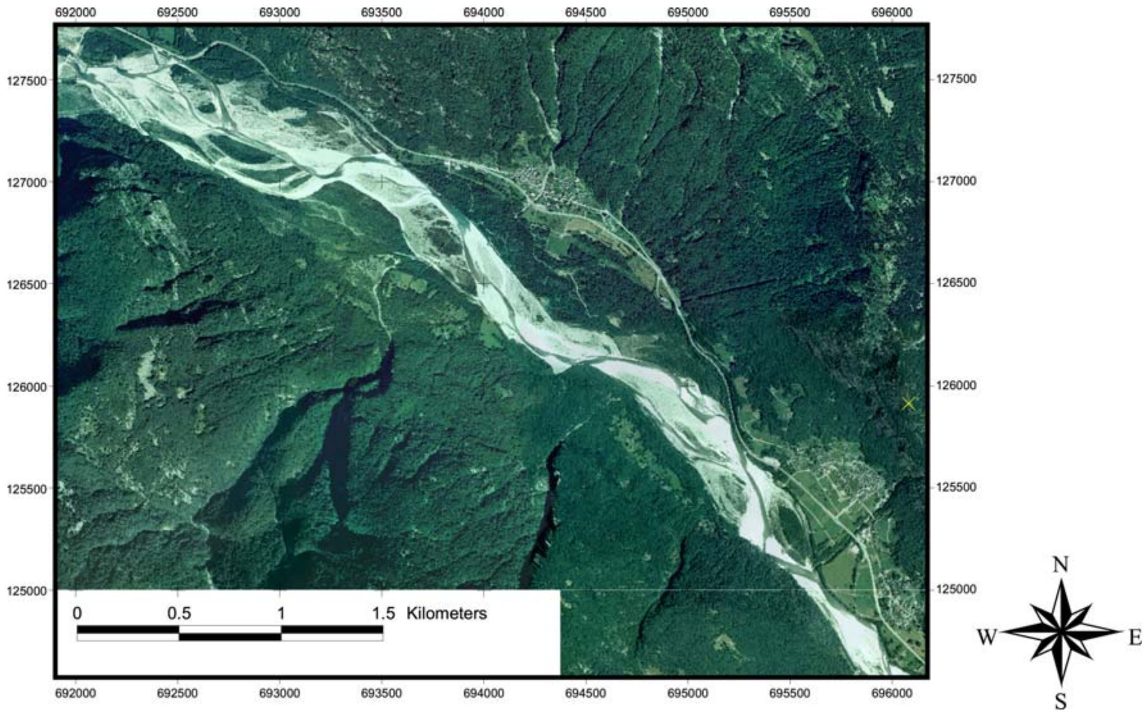

Figure 1: Aerial photograph from 26 July 1999 of the braided part of the Maggia River between the communities of Giumaglio (SE corner) and Riveo (NW corner). The study area is located near the community of Someo in the centre of the image.

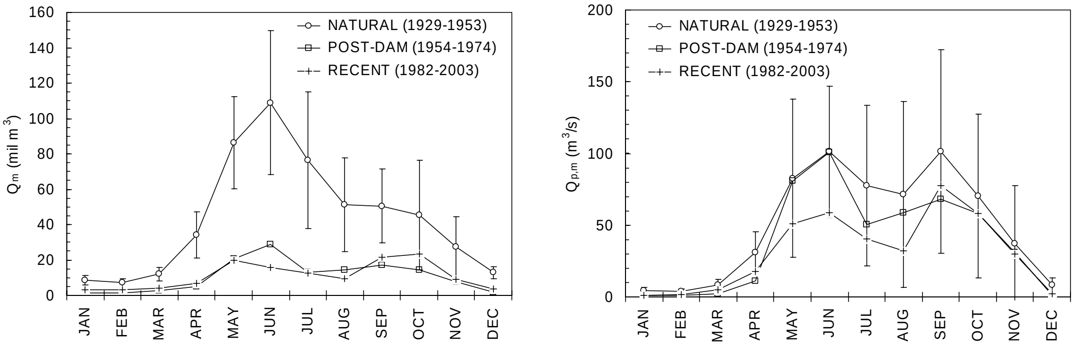

Figure 2: Seasonality of monthly streamflow Q_m (left) and daily maximum monthly streamflow $Q_{p,m}$ (right) at Bignasco (inflow into the study reach) in pre- (natural) and two post-dam periods. Markers indicate the monthly mean, bars give the range of +/- 1 standard deviation for the natural flow regime.

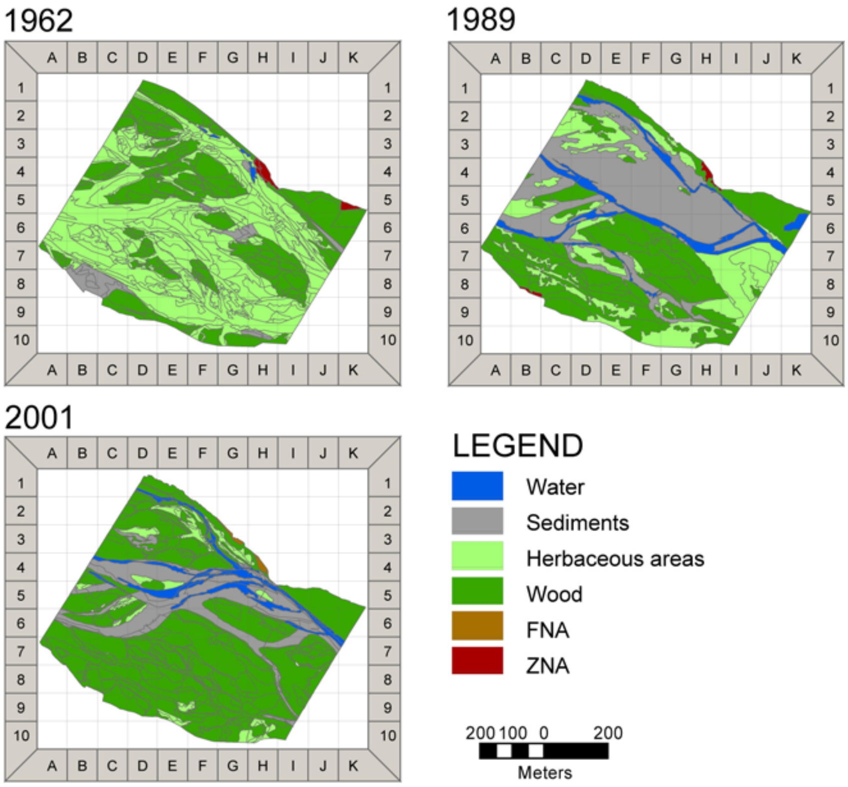

Figure 3: Classification of aerial photographs into 6 categories: water, sediment, herbaceous cover, alluvial forest, non-alluvial forest (FNA), and non-alluvial zone (ZNA) for the years 1962, 1989 and 2001 (after Favre, 2001). The study area is upstream of the bridge in Someo.

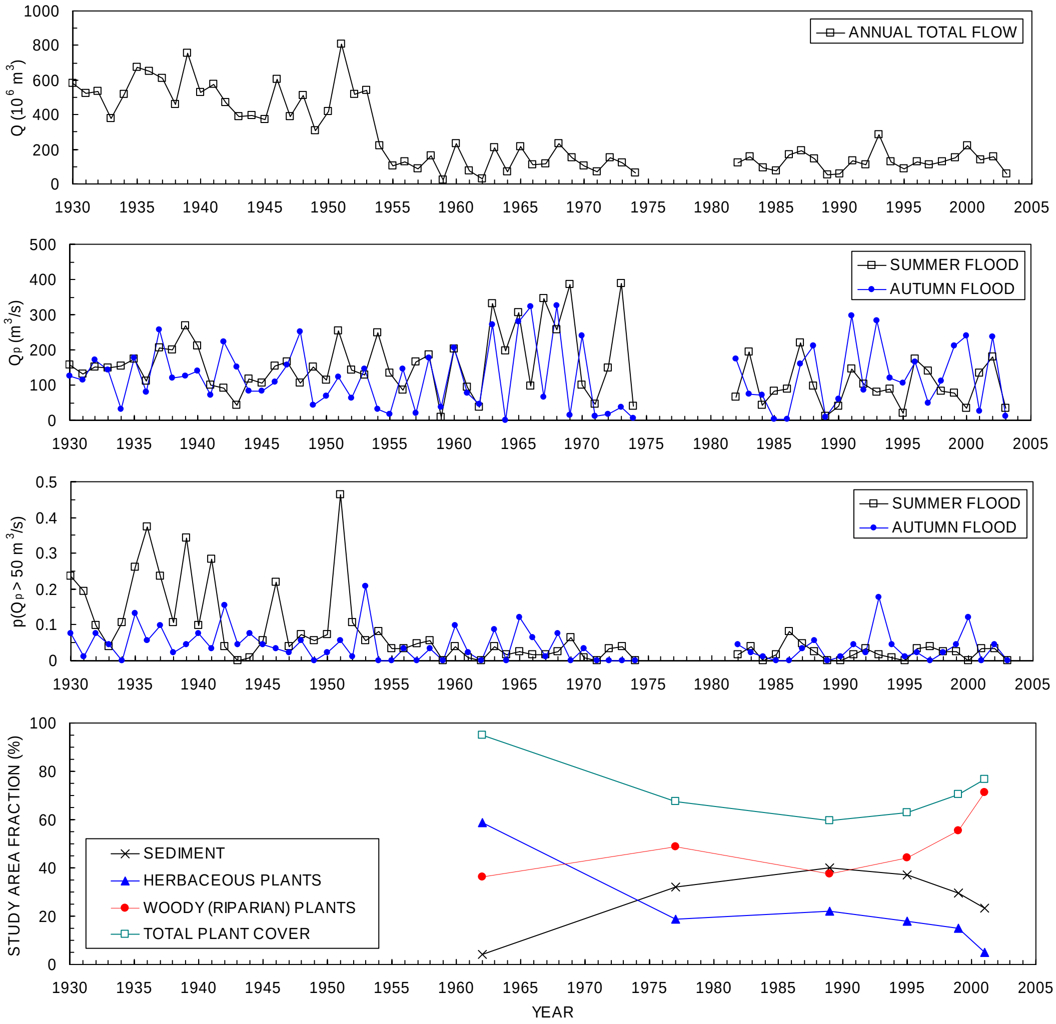

Figure 4: Time series (from top) of annual total flow, maximum summer (May-August) and autumn (September-November) annual flood peaks Q_p, the frequency of occurrence of daily flow above 50 m^3/s in the summer and autumn flood periods, and the fraction of the study area covered by sediment, herbaceous (grass/shrub) cover and woody riparian plants derived from 6 aerial scans by Favre (2004). Sediment covered area includes the exposed sediment class as well as the open water surface.