# The effect of flow regulation on channel geomorphic unit (CGU) composition in the Soča River, Slovenia.

I. Maddock & G. Hill

*Department of Applied Sciences, Geography and Archaeology, University College Worcester, Henwick Grove, Worcester, WR2 6AJ, UK.*

N. Smolar-Žvanut

*Limnos Water Ecology Group, Podlimbarskega 31, 1000 Ljubljana, Slovenia.*

ABSTRACT: This paper examines the effects of flow regulation on the size, spatial distribution and connectivity of channel geomorphic units (CGU) of the Soča River in Slovenia. A river channel survey was completed along three reaches, i.e. an unregulated stretch (reach 1), and two regulated reaches with lower discharges, (reach 2 and 3).

Results demonstrated significant differences in the CGU composition between the unregulated and regulated reaches. The unregulated stretch was dominated by the glides and relatively fast-flowing and turbulent features whilst regulated reaches were dominated by slow flowing pool CGU's. River regulation also reduced the size of the CGU's. CGU's tended to be shorter, and hence there was greater habitat division or fragmentation evident in the two regulated reaches. Therefore flow regulation in the Soča River alters the dominant types of CGU's present, significantly reduces the size of CGU's, and affects the longitudinal distribution of types by reducing habitat connectivity and creating greater habitat fragmentation.

## 1 INTRODUCTION

Physical habitat plays an important role in determining 'river health' and influencing the structure and function of aquatic communities (Stalnaker 1979, Aadland 1993, Pusey et al. 1993, Maddock 1999, Gehrke and Harris 2000, Maddock et al. 2004). Traditional assessment of both physical habitat and biotic communities (e.g. fish and macroinvertebrate populations) has tended to focus on sampling at discrete points, or along small (i.e. <200m) stretches of river channel ('small' scale). Results from sampling at disparate points are then extrapolated to the sections of river inbetween ('upscaling') to provide catchment wide assessments (at the 'large' scale), or make river management recommendations (e.g. for environmental flows). However, extrapolation without an understanding of the nature of the river between sampling points and hence a knowledge of whether they are truly representative of the river inbetween is questionable.

Furthermore, it has been argued that the an understanding of river systems at the 'intermediate' scale (i.e. 1-100 km's of stream length) may be more appropriate for studies examining physical habitat impacts on fish. Fausch et al. (2002) have argued that river habitat assessment should concentrate on assessing reaches at the 'intermediate' spatial scale rather than at disparate points or representative reaches in order to recognise the river landscape as a spatially continuous longitudinal and lateral mosaic of habitats.

To facilitate this approach, a range of river habitat mapping methods and classification systems have been developed. Surveys are normally completed as part of aquatic habitat modelling studies, either to model physical habitat availability directly from mapping results, or to identify representative reaches for further and more detailed data collection. River habitat mapping aims to identify the types and spatial configuration of geomorphic and hydraulic units. Physical habitat units have been defined and classified by many authors, leading to an array of terms in use to describe the physical environment utilised by the instream biota. The terms used to describe these units differ between authors and include 'channel geomorphic units' (CGU's) (e.g. Hawkins et al. 1993), 'mesohabitats' (e.g. Tickner et al. 2000), 'physical biotopes' (e.g. Padmore 1997) and 'hydraulic biotopes' (e.g. Wadeson 1994). Newson and Newson (2000) provide a review of the use of some of these terms and the differences between them.

Identification and mapping of channel geomorphic units can be accomplished in a variety of ways including in-channel measurements (Jowett 1993) or with the use of air photo interpretation and/or airborne multispectral digital imagery (Hardy and Addley 2001, Whited et al. 2002). The most common approach however is to walk the relevant sector of river and use subjective visual assessment (Hawkins et al. 1993, Maddock et al. 1995, Parasiewicz 2001).

In addition to the need to assess rivers at the most appropriate scale and along continuous reaches, others have called for the translation of key concepts that are well established in landscape ecology to be translated to riverine environments (Wiens 2002). These key concepts include patch dynamics, habitat connectivity, complexity and fragmentation, and the importance of understanding river ecosystems at a range of spatial scales. This requires a shift in traditional ways of conceptualising and sampling river habitats. A recent study examining macroinvertebrate assemblages has demonstrated the importance of this new approach (Heino et al. 2004). River habitat mapping is likely to underpin an understanding of the links between physical habitat dynamics and instream biota in general, and particularly for fish species.

The aim of this paper is to highlight that in addition to the routine use of habitat mapping results (to describe the types, locations and proportions of physical habitats present along a reach), these field data can also be used to evaluate habitat size, connectivity and fragmentation. This is highlighted with the use of a case study to examine the influence of flow regulation on these factors.

## 2 SITE DETAILS

The Soča River rises in the Slovenian Alps, flowing for 95km through Slovenia before crossing into Italy and discharging into the Adriatic Sea. It has a catchment area of 1576 $km^2$ and is predominantly underlain by limestone, but the lower parts the river run over flysch and quaternary gravels. The Soča has a flashy flow regime, with high flows occurring at any time of year. The lowest flows are experienced both in summer and winter months with generally higher snow-fed flows in spring and rain fed flows in autumn. The Soča River is well known for the presence of Marble Trout and recreational (white-water rafting) opportunities.

The river is regulated for hydro-power production at the Podsela Dam and Ajba Dam. Water is abstracted from the impoundment upstream from each dam. It then flows along a bypass channel to the hydropower plant and is subsequently augmented back to the river channel further downstream. Therefore, bypassed sections with reduced flows exist below each dam.

No long term flow records are available to describe the pre- and post river regulation flow regimes exactly, but it is clear that the hydro-power scheme abstracts the vast majority of water for long periods of time, leaving by-passed sections of river with greatly reduced flows. Prior to 2001, the highest possible abstraction rate at Podsela Dam was 96 $m^3s^{-1}$ and the measured flow below the Podsela Dam for most of the year is 0.2 $m^3s^{-1}$. The highest possible abstraction rate at the Ajba Dam is 75 $m^3s^{-1}$ whilst flow releases until 2003 were normally 0.5 $m^3s^{-1}$.

In order to assess the impact of these reduced flows on physical habitat type, size and fragmentation, three reaches of river were assessed. **Reach 1:** an unregulated 5.14km stretch of the river between Volarje and Tolmin flowing through a broad open floodplain; **Reach 2:** on a 4.20km by-passed section of the river affected by abstraction below the Podsela Dam that flows through a confined river valley bordered by bedrock walls; and **Reach 3:** another regulated part of the river below the Ajba Dam (4.95km long) with a relatively intermediate-sized valley floor. The three reaches are illustrated in Figure 1 below.

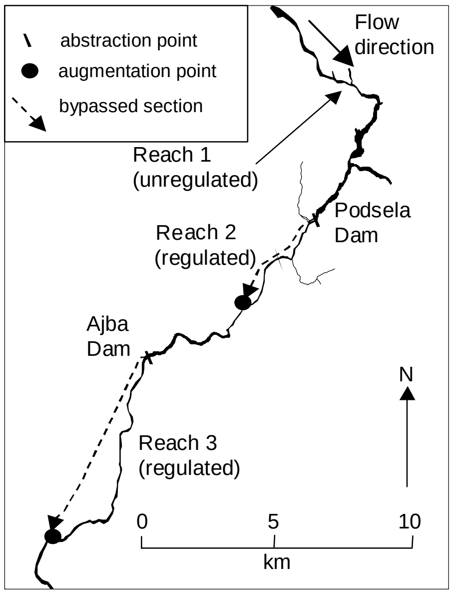


Figure 1. Site Location.

## 3 METHODS

Each reach was mapped to examine CGU composition and distribution. Mapping was undertaken between 5th–8th July 2004 inclusive, following established procedures (Maddock and Bird, 1996). Each reach was navigated primarily on foot; a small boat was used to traverse the non–wadeable reaches. Field assessment involved a combination of visual assessment and physical measurement. CGU's were identified using a modified version of the Hawkins et al. (1993) classification system. Descriptions of CGU's are highlighted in Table 1.

Boundaries between each CGU were visually identified from the bankside or boat, and their locations mapped using a Trimble GeoXT 12 channel GPS receiver with sub-metre accuracy. Channel width and water width were recorded to the nearest metre using a Bushnell Yardage Pro distance measurer at a representative point within each CGU.

Table 1. Description of Channel Geomorphic Units (after Hawkins et al. 1993).

| CGU (Mesohabitat) | Turbulence | Brief Description |
|---|---|---|
| Fall (Fa) | Turbulent & Very Fast | Vertical drops of water over a full span of the channel, commonly found in bedrock and step-pool stream reaches. |
| Cascade (Ca) | Turbulent & Very Fast | Highly turbulent series of short falls and small scour basins, frequently characterised by very large substrate sizes and a stepped profile; prominent features of bedrock and upland streams. |
| Chute (Ch) | Turbulent & Very Fast | Narrow steep slots or slides in bedrock. |
| Rapid (Ra) | Turbulent & Fast | Moderately steep channel units with coarse substrate, but unlike cascades posses a planar rather than stepped profile. |
| Riffle (Ri) | Turbulent & Moderately Fast | The most common type of turbulent fast water CGU's in low gradient alluvial channels. Substrate is finer (usually gravel) than other fast water turbulent CGU's, and there is less white water, with some substrate breaking the surface. |
| Run (Ru) | Less Turbulent & Moderately Fast | Moderately fast and shallow gradient with ripples on the surface of the water. Deeper than riffles with little if any substrate breaking the surface. |
| Glide (Gl) | Non-Turbulent Moderately Slow | Smooth 'glass-like' surface with visible flow movement along the surface; relatively shallow (compared to pools). |
| Pool (Pl) | Non-Turbulent & Slow | Relatively deep and normally slow flowing, with finer substrate. Usually little surface water movement visible. Can be bounded by shallows (riffles, runs) at the upstream and downstream ends. |
| Ponded (Pd) | Non-Turbulent & Slow | Water is ponded back upstream by an obstruction, e.g. weir, dam, sluice gate etc. |
| Other (O) | | Used in unusual circumstances where feature does not fit any of recognised types. |

Substrate sizes present (based on the Wentworth classification) were identified and assigned to 'dominant', 'subdominant' and 'present' categories. Maximum depth for each CGU was estimated to the nearest cm using a measuring staff and the average water column velocity was measured at 0.6 of the water depth from the surface, using a SEBA Mini Current Meter in order to confirm hydraulic characteristics within and between CGU's. The proportion of the surface area of each CGU taken up with instream cover (e.g. instream macrophytes, large woody debris) and overhanging cover (e.g. from overhanging trees and boughs) were visually estimated to the nearest 10 percent. The presence of lateral-, point- and mid-channel bars, their location (e.g. left or right bank), and whether they were vegetated (>50% of surface covered) or unvegetated (<50%) were also noted to provide additional descriptive information. Photographs were taken of each CGU and their numbers recorded.

Using MapInfo 7.5 software, GPS data were combined with digitised maps at 1:50,000 scale and data recorded during the survey to create maps showing the CGU locations. The measured width and length data were used to calculate total water area in each reach and for individual CGU types in each reach.

## 4 RESULTS

Results demonstrated significant differences in the CGU composition between the unregulated and regulated reaches (Fig. 2).

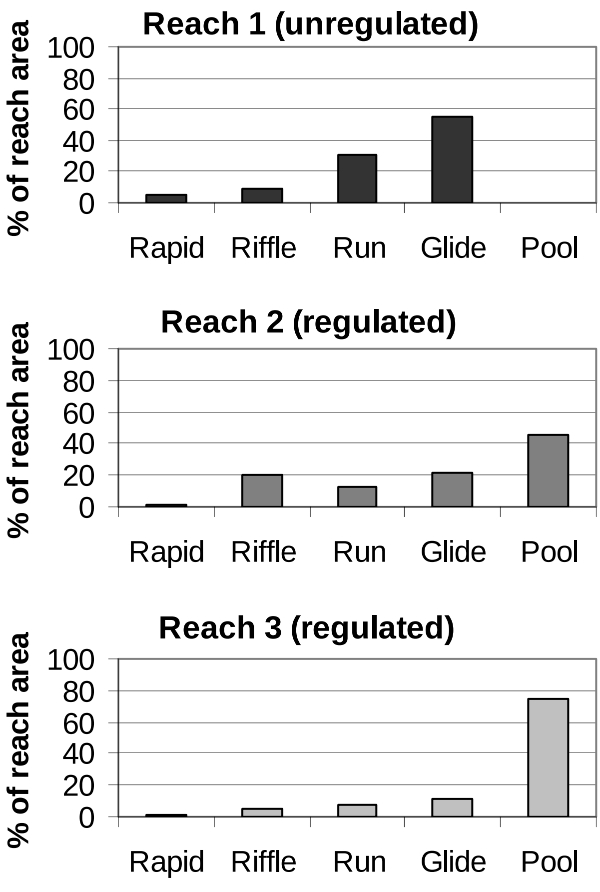


Figure 2. CGU proportions in each reach.

A reach dominated by fast and turbulent CGU's will have bars focused on the left-hand side of the diagram. As bars become increasingly skewed towards the right-hand side, then this indicates the channel is dominated by slower flowing and non-turbulent CGU's.

The unregulated stretch (reach 1) was dominated by the glides (55%) with the rest of the reach consisting of relatively fast-flowing and turbulent features (runs, riffles and rapids). The dominant feature of both of the regulated reaches were the slow flowing pool CGU's occupying 44% of reach 2, and 76% of reach 3, with glides, runs, riffles and rapids forming the remainder of the CGU's.

Physical measurements of CGU length and water width enabled the calculation of the extent that the reduced discharge in the regulated reaches was dewatering the channel and reducing the size of the CGU's (Table 2).

Table 2. Length and average water width of each reach

| Reach No. | Length (km) | Average CGU water width (m) |
|---|---|---|
| Reach 1 (unregulated) | 5.142 | 58.0 |
| Reach 2 (regulated) | 4.195 | 18.4 |
| Reach 3 (regulated) | 4.949 | 29.2 |

The average CGU size in the unregulated stretch (reach 1) was 58m wide, compared to 18.4m in reach 2, and 29.2m in reach 3. A direct comparison of CGU size (width and length) is illustrated in Figure 3 below. This highlights the impact of flow regulation in reducing average CGU size in reach 2 and reach 3.

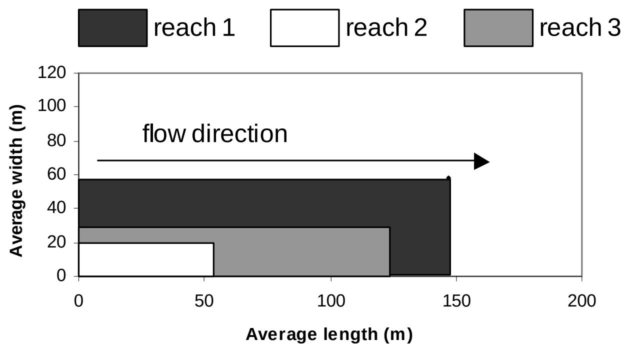


Figure 3. Average length and width characteristics of CGU's in each reach.

In order to examine the effect of regulation on the degree of CGU fragmentation, the average number of units per km was calculated. A relatively large number indicates the channel is dominated by more CGU's and hence they are shorter and more fragmented, whereas a smaller number indicates the reach has fewer units occupying greater longitudinal distances. Results are illustrated for each reach in Table 3 below.

CGU's tended to be shorter, and hence there was greater habitat division or fragmentation evident in the two regulated reaches, particularly reach 2 (18.12 CGU's per km) compared to the unregulated reach (6.81 CGU's per km).

Table 3. Number and fragmentation of CGU's along each reach.

| Reach No. | Length (km) | Total number of CGU's along reach | Number of CGU's per km |
|---|---|---|---|
| Reach 1 (unregulated) | 5.142 | 35 | 6.81 |
| Reach 2 (regulated) | 4.195 | 76 | 18.12 |
| Reach 3 (regulated) | 4.949 | 40 | 8.08 |

## 5 DISCUSSION AND CONCLUSION

This study demonstrates that when utilising river habitat mapping results in the routine sense, i.e. to examine the types and proportions of CGU's present in discrete reaches, the impacts of river regulation are evident. Using the case study of the Soča River, the unregulated reach was dominated by glides and relatively fast-flowing features, whereas the effects of abstraction in the regulated sections created reaches dominated by slow flowing pool type CGU's. The effects of local geomorphology, such as valley gradient and width are also likely to influence CGU presence and when conducting a field-based study such as this, these factors cannot be controlled between reaches. However, reach 1 occupies a broad, wide open floodplain, and reach 2 a narrow confined valley. The confinement in reach 2 may be expected to constrain channel and water width and lead to increased water velocities and a greater proportion of fast flowing turbulent units here. Despite this, the opposite is true; reach 2 has a greater proportion of slow flowing (pool) units than reach 1, demonstrating that the impact of river regulation is evident from habitat mapping results despite influences of channel morphology rather than because of them.

Reduced discharges from abstraction in the downstream reaches (2 and 3) has significantly reduced average water width when compared to the unregulated reach upstream (to 31.8% and 50.4% respectively). More importantly, lower flows have increased the average number of units per km in these stretches. It is possible to interpret this as a positive effect, with increased number of units representing greater physical diversity and therefore likely to support enhanced biodiversity. However, we suggest the overall effect is a negative one, because although regulated reaches are dominated by more units, but these are significantly smaller (narrower and shorter) and are more isolated or fragmented. This effect is illustrated in the Figure 4 where the regulated reach plots in the lower right-hand corner, but increasing abstraction and reduction in flow creates narrower and shorter units and hence reach results plot in the upper left-hand corner.

It is highly likely that there will be a relationship between the diversity (number of types) of CGU's present and flow, the exact nature of which will be partly controlled by local geomorphology. At high flows, reaches will be dominated by a small number of fast and turbulent CGU's (e.g. rapids and runs). At intermediate flows, diversity will higher, with the additional presence of riffles (formerly submerged at high flows), glides and possibly some pools. As flow decline to relatively low flows, CGU diversity will decrease again, with slow flowing and non-turbulent types (glides and pools) dominating, interspersed with runs and riffles at isolated locations where local geomorphology creates an increased gradient. The exact relationship will clearly be controlled by the valley gradient and local geomorphology.

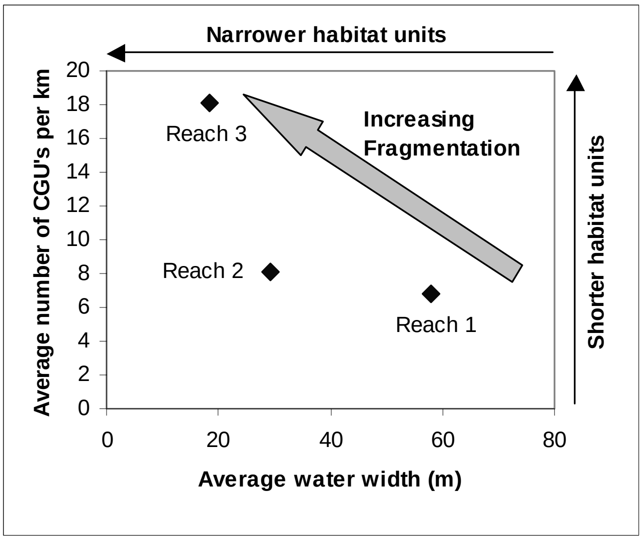


Figure 4. Average width and length relationships as an indicator of habitat fragmentation in each reach.

The preliminary results presented here provide a basis on which to interpret habitat mapping data to compare habitat size and fragmentation along continuous stretches at the intermediate scale. This study suggests that in the Soča River under the flow conditions present during the survey, flow regulation alters the dominant types of CGU's present (to slower flowing and less turbulent features), significantly reduces the size of CGU's, and affects the longitudinal distribution of types by reducing habitat connectivity and creating greater habitat fragmentation.

Further research that examines the temporal dynamics of habitat composition along the same reach (and hence negates the impact of different geomorphological controls operating on different reaches) at a range of flows would be very valuable. This may identify critical parts of the flow regime when significant changes in habitat diversity (i.e. how many types of CGU's are present), size and fragmentation occur. This in turn may be useful for environmental flow determination. The objective identification of units is also clearly important in any such assessment and this relies on reliable and repeatable assessment methods. Whilst visual identification from the bankside goes some way to accomplishing this, it is likely that technological advances in the use of remote sensing and airborne multispectral digital imagery (Whited et al. 2002) will increase the speed of data collection. Subsequent image analysis could also enable improved and more robust classification of hydraulic and geomorphic units. More fundamentally, ecological validation of CGU's and the exact requirements of stream communities in terms of habitat size, diversity and fragmentation is required to ensure the relevance of the habitat units being mapped, and to strengthen our knowledge of flow-habit-biota relationships.

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