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A COMPARISON OF THE CHANNEL GEOMORPHIC UNIT COMPOSITION OF REGULATED AND UNREGULATED REACHES IN THE SOČA RIVER

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Abstract
A comparison of the channel geomorphic unit composition of regulated and unregulated reaches in the Soča river
This paper examines the effects of flow regulation on the size, spatial distribution and connectivity of channel geomorphic units (CGU) in the Soča River, Slovenia. A river channel survey was completed along three reaches, i.e. an unregulated reach (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. 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.

Key words
Soča River, river regulation, habitat mapping, channel geomorphic unit, river hydraulics, river morphology

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1. Introduction

Physical habitat in rivers is determined by the interaction of geomorphology and hydrology. It 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 individual points or cross-sections, or along small (i.e. <200m) stretches of river channel. Results from sampling at separate points are then extrapolated to the sections of river inbetween to provide catchment wide assessments, 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.

Fausch et al. (2002) have argued that river habitat assessment should concentrate on assessing longer reaches 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. For the purposes of this paper, we refer use the term 'channel geomorphic units', defined as 'areas of relatively homogeneous depth and flow that are bounded by sharp gradients in both depth and flow' (Hawkins et al. 1993, 3).

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. 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 examine the influence of flow regulation in the Soča river on the types, locations and proportions of physical habitats, and to evaluate habitat size, connectivity and fragmentation

2. Site details

The Soča River rises in the Slovenian Alps, flowing for 95 km 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 of the river run over flysch and quaternary gravels. The Soča River 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.

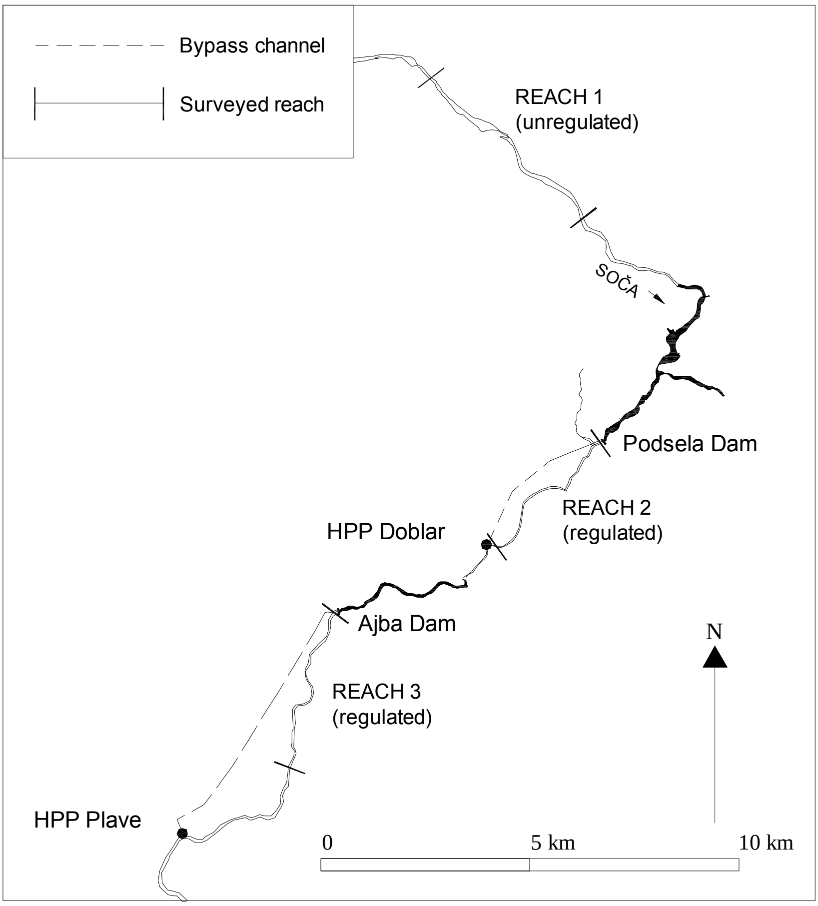

Fig. 1: Site location on the Soča River.

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 further downstream where it is subsequently augmented back to the main river channel. Water from Podsela Dam is diverted to the Doblar Hydropower Plant (HPP Doblar) and from Ajba Dam to the Plave Hydropower Plant (Plave HPP). Therefore, river sections with reduced flows exist below each dam (Fig. 1). Prior to 2001, the highest possible abstraction rate at Podsela Dam was 96 m^3/s and the measured flow below the Podsela Dam for most of the year was 0.2 m^3/s. Since 2001, the highest possible abstraction has been increased to 180 m^3/s. The highest possible abstraction rate at the Ajba Dam was 75 m^3/s prior to 2001 and 180 m^3/s since 2001 (Smolar-Žvanut 2001). A summary of flow statistics is provided in Tab. 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 5.14 km stretch of the river between Volarje and Tolmin flowing through a broad open floodplain (Fig. 2); Reach 2: on a 4.20 km by-passed section of the river affected by abstraction below the Podsela Dam that flows through a confined river valley bordered by bedrock walls (Fig. 3); and Reach 3: another regulated part of the river below the Ajba Dam (4.95 km long) with a relatively intermediate-sized and open valley floor (Fig. 4). The gradient in the Soča river is 2.8 %o to 2.9 ‰ between Kobarid and Tolmin (reach 1), 5.3 ‰ between Podsela and Avče (reach 2) and 2.66 ‰ between Avče and Rodež (reach 3) (Ilešič 1951).

Tab. 1: Hydrological parameters for the Soča River in the different reaches for the period 1961-1995 (modified from Smolar-Žvanut 2001).

Site Location	Reach these data represent	Catchment Area (km^2)	Mean Annual Flow (m^3/s)	Mean Minimum Flow (m^3/s)	Minimum Recorded Flow (m^3/s)
Soča River at the Podsela Dam	Downstream from Reach 1	1244	80.0	16.0	10.0
Soča River downstream of the Podsela Dam – with abstraction 96 m^3/s (typical prior to 2001)	Reach 2	1254	22.5	0.13	0.12
Soča River downstream of the Podsela Dam – with abstraction 180 m^3/s (typical after 2001)	Reach 2	1254	12.2	0.13	0.12
Soča River downstream of the Ajba Dam – with abstraction 75 m^3/s (typical prior to 2001)	Reach 3	1345	33.1	1.0	1.0
Soča River downstream of the Ajba Dam – with abstraction 180 m^3/s (typical after 2001)	Reach 3	1345	16.3	1.0	1.0

Fig. 2: The Soča River in Reach 1.

Fig. 3: The Soča River in Reach 2.

Fig. 4: The Soča River in Reach 3.

3. Methods

Habitat mapping was undertaken between 5^{th}–8^{th} 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 Tab. 2.

Habitat mapping started at the selected upstream end and we noted the first CGU type and location. 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. The measured width and length data were used to calculate total water area in each reach and for individual CGU types in each reach.

Tab. 2: Description of Channel Geomorphic Units (after Hawkins et al. 1993).

CGU (Mesohabitat)	Turbulence	Brief Description
Fall	Turbulent & Very Fast	Vertical drops of water over a full span of the channel, commonly found in bedrock and step-pool stream reaches.
Cascade	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	Turbulent & Very Fast	Narrow steep slots or slides in bedrock.
Rapid	Turbulent & Fast	Moderately steep channel units with coarse substrate, but unlike cascades posses a planar rather than stepped profile.
Riffle	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	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	Non-Turbulent Moderately Slow	Smooth 'glass-like' surface with visible flow movement along the surface; relatively shallow (compared to pools).
Pool	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	Non-Turbulent & Slow	Water is ponded back upstream by an obstruction, e.g. weir, dam, sluice gate etc.
Other		Used in unusual circumstances where the feature does not fit any of the other types defined above.

Substrate sizes present (based on the Wentworth classification) were identified and assigned to 'dominant', 'subdominant' and 'present' categories for descriptive purposes. Mean water 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. Photographs were taken of each CGU and their numbers recorded.

During the field surveys, flow in the unregulated reach (Reach 1) was 27.7 m^3/s, (recorded at the Log Čezsoški gauging station located approximately 30 km upstream). Flow in the regulated Reach 2 downstream of the Podsela Dam was 1.55 m^3/s, and flow in the regulated Reach 3 downstream of the Ajba Dam was 1.67 m^3/s (both measured manually using a SEBA Mini Current Meter).

4. Results

Results demonstrated significant differences in the CGU composition between the unregulated and regulated reaches. The unregulated stretch (reach 1) was dominated by glides (55 %) (Fig. 5) 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 (Fig. 6), and 76 % of reach 3 (Fig. 7), 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 (Tab. 3). The average CGU size in the unregulated stretch (reach 1) was 58 m wide, compared to 18.4 m in reach 2, and 29.2 m in reach 3. A direct comparison of CGU size (width and length) is illustrated in Fig. 8. This highlights the impact of flow regulation in reducing average CGU size in reach 2 and reach 3.

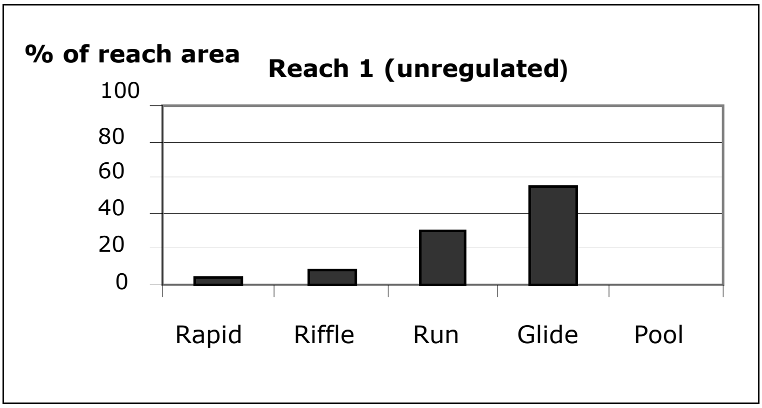

Fig. 5: CGU proportions in reach 1.

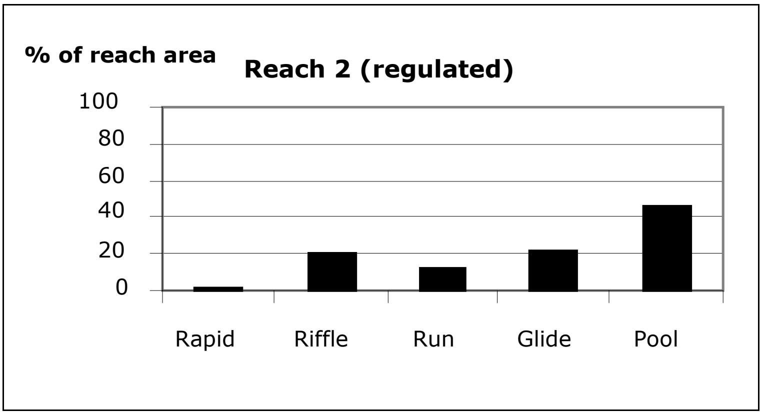

Fig. 6: CGU proportions in reach 2.

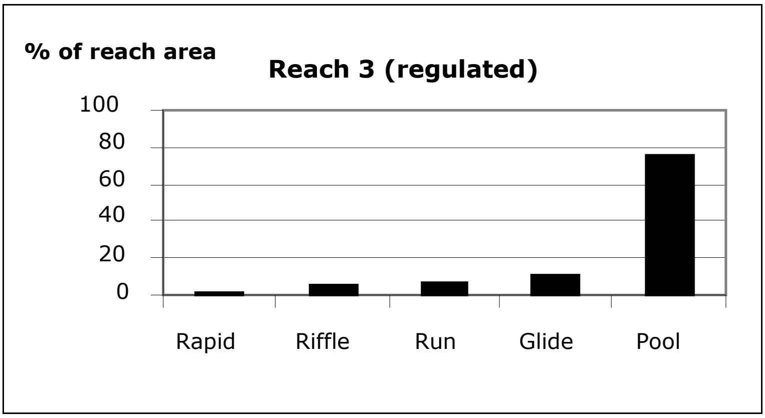

Fig. 7: CGU proportions in reach 3.

Tab. 3: 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

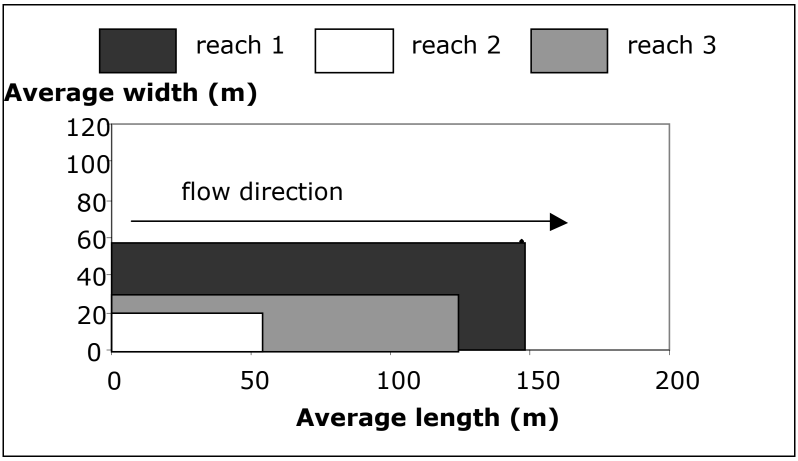

Fig. 8: Average length and width characteristics of CGU's in each reach.

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 reach 2 (18.12 CGU's per km) is dominated by more CGU's and hence they are shorter and more fragmented, whereas a smaller number at reach 1 and reach 3 indicate both reaches have fewer units occupying greater longitudinal distances (6.81 CGU's per km in reach 1 and 8.08 CGU's per km in reach 3). Results are illustrated for each reach in Tab. 4.

Tab. 4: 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

Mean water depth and mean water velocity data from each CGU were analysed to assess the variation in hydraulic characteristics between reaches and between CGU types (Tab. 5). Reach 1 has a greater mean depth (1.25 m) and velocity (1.02 m/s) than the two regulated reaches because of the significantly higher discharge present in reach 1. Comparing the two regulated reaches, Reach 2 has shallower water and faster velocities than reach 3. This is caused by reach 2 having a greater proportion of riffles, runs and glides and a more constrained valley width, whereas reach 3 is dominated by slow flowing pool type habitats and has a wider channel with an open valley floor.

Tab. 5: Hydraulic characteristics of CGU's in each reach.

	Mean Water Depth (m)	Mean Water Velocity (m/s)
Reach 1		
Rapid	1.50	1.50
Riffle	0.77	1.14
Run	1.33	0.99
Glide	1.21	0.89
Pool	none present	none present
Reach Average	1.25	1.02
Reach 2		
Rapid	0.91	1.55
Riffle	0.26	0.90
Run	0.33	0.77
Glide	0.45	0.46
Pool	1.27	0.16
Reach Average	0.59	0.60
Reach 3		
Rapid	0.35	0.61
Riffle	0.31	0.82
Run	0.49	0.77
Glide	0.48	0.31
Pool	1.89	0.04
Reach Average	0.85	0.43

In each reach, these data also confirm the transition between CGU's types, with rapids being characterised by the highest velocities, then riffles, runs, glides and finally pools with the lowest velocities. The exception is found in the Ajba reach where riffles have a higher velocity on average to the rapids. This can be explained by the fact that only one rapid was present in this reach and hence a small sample size influences the results. Riffles are the shallowest CGU types in each reach and pools the deepest. Runs and glides tend to be characterised by similar water depths, but are differentiated by their velocities, with glides having lower water velocities, particularly in the two regulated reaches.

5. Discussion

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 continuous reaches, the impacts of river regulation are evident. In 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). The exact effect of river regulation on water width is determined by a combination of channel morphology and the severity of regulation and so will vary between sites. However, these figures compare favourably with those of Surian (1999) who discovered a 35 % reduction in channel width due to long term river regulation on the Piave River in Italy, and Petts et al. (1993) who found a 53 % lowering of channel width on the River Rede, UK under similar circumstances.

More importantly, lower flows have increased the average number of units per km in these stretches. Similar findings were observed recently in the Bistrica River (Smolar-Žvanut et al, 2005). It is possible to interpret this as a positive effect, with an increased number of units representing greater physical diversity and therefore one may consider this likely to support enhanced biodiversity. However, we suggest the overall effect is a negative one, because although regulated reaches are dominated by more CGU's, these CGU's are significantly smaller (narrower and shorter) and in particular are more isolated or fragmented (Fig. 9).

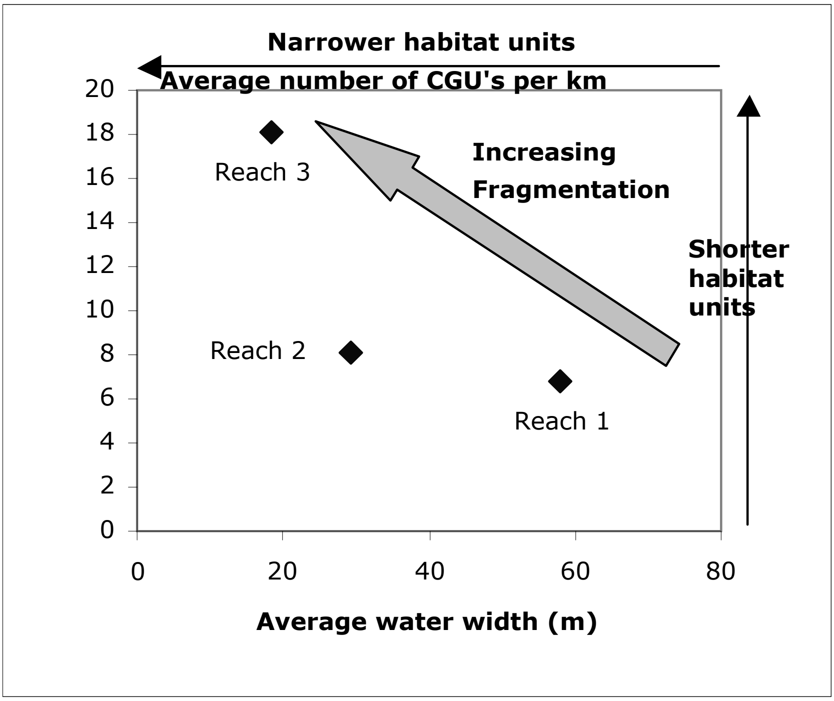

Fig. 9: Relationship between average width and the number of CGU's per km as an indicator of habitat fragmentation in each reach.

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 declines 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 nature of this relationship will be controlled by the valley gradient and local geomorphology.

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.

6. Conclusion

The results presented here provide a basis on which to interpret habitat mapping data to compare habitat size and fragmentation along continuous stretches.. 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 is needed to understand the relationship between physical habitat dynamics and stream communities. This relationship is undoubtedly a complex one, but some work has already examined the link between hydrology and phytobenthos populations in the Tržiška Bistrica River (Smolar-Žvanut et al. 1998), the Soča River (Smolar-Žvanut et al. 2004a) and the Branica River (Smolar-Žvanut et al. 2004b) in order to make recommendations for environmental flows. Further studies of this nature would be beneficial, and research that can provide ecological validation of CGU's and identify the exact requirements of stream communities in terms of habitat size, diversity and fragmentation is required. This work would ensure the habitat units being mapped are ecologically relevant, and strengthen our knowledge of flow-habitat-biota relationships.

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PRIMERJAVA GEOMORFOLOŠKIH ENOT STRUGE V REGULIRANIH IN NEREGULIRANIH ODSEKIH REKE SOČE

Povzetek

Namen članka je ugotoviti vpliv regulacije pretoka vode v reki Soči na tipe, velikost, prostorsko porazdelitev in povezanost geomorfoloških enot struge (GES).

Raziskavo smo opravili na treh odsekih reke, tj. na nereguliranem odseku (odsek 1) in na dveh reguliranih odsekih z zmanjšanima pretokoma vode (odseka 2 in 3). Vse tri odseke vodotoka smo prehodili ob oziroma v strugi, z majhnim čolnom pa smo prečkali neprebrodljive odseke. Ocenjevanje na terenu je obsegalo kombinacijo vizualnih in fizičnih meritev.

Rezultati so pokazali znatne razlike v sestavi GES med reguliranimi in nereguliranimi odseki reke. Na nereguliranem odseku reke Soče so prevladovali gladki tokovi in habitati z značilno hitrim vodnim tokom, medtem ko so na reguliranih odsekih reke Soče prevladovali tolmunski tipi GES s počasnim vodnim tokom. Zaradi odvzemov vode in s tem zmanjšanih pretokov reke na odsekih 2 in 3 je prišlo do znatnega zmanjšanja v povprečni širini omočenosti struge v primerjavi z nereguliranim odsekom (na 31,8 % in 50,4 %). Še večjega pomena je dejstvo, da je v reguliranih odsekih reke naraslo povprečno število GES na km.

Rezultati raziskav predstavljajo osnovo, na podlagi katere lahko razlagamo podatke o kartiranih habitatih ter interpretiramo velikost in fragmentacijo habitatov vzdolž zaporednih odsekov reke. Rezultati študije so pokazali, da je regulacija pretoka reke Soče vplivala na spremembo prevladujočega tipa GES, znatno zmanjšala velikost GES in vplivala na dolžinsko razporeditev tipov GES. Zmanjšala se je povezanost habitatov, fragmentacija habitatov pa se je povečala. V prihodnosti je potrebna izvedba raziskav, ki bodo prispevale k boljšemu razumevanju odnosov med dinamiko fizičnega habitata in združbami oranizmov v vodotoku.