

RIVER HABITAT AND MACROPHYTE SURVEYS IN THE HIGH TATRA MOUNTAINS OF SLOVAKIA AND POLAND

Results from 2010

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PURPOSE

The main objective of our study visit (6th to 12th June 2010) was to characterise the habitats and aquatic macrophyte flora of near-natural streams in the High Tatra mountains (Slovak: Vysoké Tatry; Polish: Tatry Wysokie; High Tatras) and to use the results for benchmarking purposes.

Specific objectives were to:

- assess the habitat character of several high altitude streams, using River Habitat Survey (RHS)¹, and the macrophyte flora using the Joint Nature Conservation Committee (JNCC)² and Mean Trophic Ranking (MTR)³ methods;
- establish a baseline dataset of RHS and macrophyte results and add this information to the database already established for the Standardisation of River Classifications (STAR) project⁴;
- assess the effect of different survey lengths by comparing results from consecutive RHS surveys, and establish an optimum sampling strategy;
- recommend improvements to the RHS manual for use in Poland⁵ and Slovakia;
- test the CEN guidance standard on the hydromorphological assessment of rivers⁶;
- develop cross-border survey work between Slovakia and Poland and foster closer collaboration on river assessment methods between Britain, Slovakia and Poland.

We also took the opportunity to sample benthic macroinvertebrates near some of the RHS sites.

Results are presented in Tables and Figures, with supporting material in Appendix 1 and Annexes A-L. Recommendations for improving the RHS manual are set out in Appendix 2.

BACKGROUND TO METHODS

River Habitat Survey

River Habitat Survey is a method developed in the UK to characterise and assess, in broad simple terms, the physical

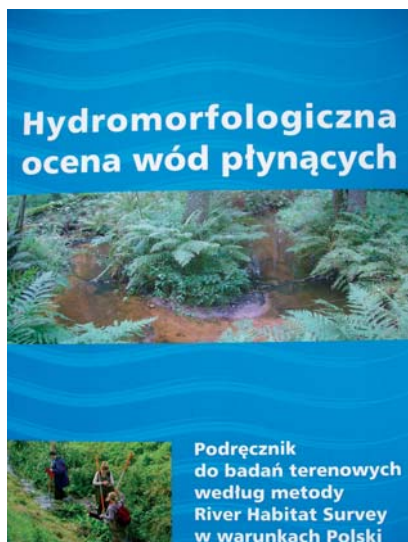
character of freshwater streams and small rivers. It is carried out along a 500m length of river. Observations on channel features and modifications are made at 10 equally spaced spot-checks, together with an overall “sweep-up” summary for the whole site. Other information such as valley form and land-use in the river corridor is also collected. Field survey follows the strict protocols given in the 2003 RHS manual¹ and surveyors in the UK are required to be fully trained and accredited.

Beyond the UK, RHS has also been carried out in several other European countries. For instance, more than 200 RHS surveys were included during the STAR project⁴; in addition, 200 sites have been surveyed in Italy; more than 600 in Poland, over 700 in Portugal and almost 800 in the Cantabrian Region of northern Spain. The RHS manual has been adapted and translated into Italian, French and Polish⁵, whilst Portuguese and Spanish versions have also been developed.

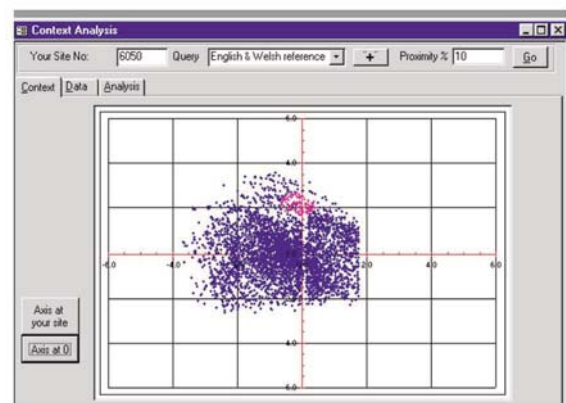
RHS survey data and site photographs are entered onto a computer database. The UK database now contains field observations, map-derived information and photographs from more than 24,000 surveys undertaken since 1994. During 1994-96, a stratified random network of nearly 5000 sites provided baseline information about the physical character from a geographically representative sample of streams and rivers across the UK⁷. A second survey in England and Wales was carried out during 2007 and 2008 and summary information, including changes since the original baseline, was published in October 2010 (<http://www.environment-agency.gov.uk/research/library/publications/123383.aspx>).

The RHS database allows sites of a similar nature to be grouped together for comparative purposes. Channel slope, distance from source, height of source and site altitude are used to cluster RHS sample sites for so-called “context analysis” based on Principal Components Analysis (PCA) plots⁸. A more sophisticated context analysis, using field survey data to derive seven indices of river channel character has now been developed⁹.

The RHS database allows detailed investigation of the relationships between physical variables (e.g. gradient, geology), channel modifications and habitat features at spot-check and 500m site level. These investigations can make use of available water chemistry and hydrological data, plus survey results of benthic macroinvertebrates, aquatic macrophytes, fish and breeding water birds where biological sampling has been done in or near RHS sites¹⁰.



The 2009 Polish RHS manual.



Principal Components Analysis allows comparison of similar river sites, based on map data.



Diversity of flow, channel substrata and habitats produces a high HQA score.

Assessment of habitat quality and extent of channel modification can be derived from RHS data, and these indices used as a basis for setting physical quality objectives for rivers¹¹. For example, **Habitat Quality Assessment (HQA)** is a broad indication of overall habitat diversity provided by natural features in the channel and river corridor. Points are scored for the presence of features such as point, side and mid-channel bars, eroding cliffs, large woody debris, waterfalls, backwaters and floodplain wetlands. Additional points reflect the variety of channel substrata, flow-types, in-channel vegetation, and also the distribution of bank-side trees and the extent of near-natural land-use adjacent to the river. Points are added together to provide the HQA score¹².

In contrast to HMS (*described below*), higher HQA scores represent more diverse sites. The character and pattern of features in a site is influenced by natural variation and also the extent of human intervention both in the channel and adjacent land. The RHS database allows HQA scores to be compared using sites with similar physical characteristics (e.g. gradient, distance from source) and geology. Features determining habitat suitability for individual species such as European river otter *Lutra lutra* and dipper *Cinclus cinclus* can also be used as attributes, thereby providing a more sophisticated species or community-based context for comparing sites¹².

Carrying out RHS and aquatic macrophyte surveys in reaches of known good or high quality has provided calibration of HQA across a wide range of river types¹³. Between 1994 and 2009, this 'benchmarking' exercise involved 181 RHS sites on 82 rivers in Britain and Ireland. Specially targeted 'benchmark' surveys have been extended to mainland Europe, including rivers in Finland, Norway, Slovenia, Bavaria, the Tyrolean Alps, the Cévennes in south-eastern France, Poland, the Picos de Europa of northern Spain and the Mediterranean area of southern Portugal¹⁴⁻²⁰. The High Tatras represent the latest study area in this mainland European work which now comprises 133 RHS sites on 66 streams and rivers. Comparison of RHS and other habitat assessment methods has also been part of this European-wide initiative²¹.

Habitat Modification Score (HMS) is an indication of artificial modification to river channel morphology. To calculate the HMS for a site, points are allocated for the presence and extent of artificial features such as culverts and weirs and also modifications caused by the re-profiling and reinforcement of banks. Greater and more severe modifications result in a higher score. The cumulative



Artificial bank reinforcement and reprofiling produces a high HMS score.

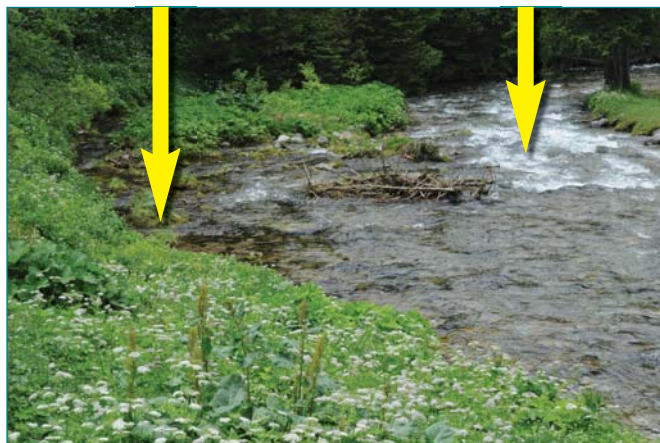
points total provides the Habitat Modification Score (HMS). A Habitat Modification Class (HMC) protocol has been developed which allocates the condition of the channel in a site to one of five modification classes, based on the total score (1 = near-natural; 5 = severely modified). In contrast to HQA, higher HMS scores reflect more artificial intervention and modification of the river channel within a site.

RHS made an important contribution to development of the CEN guidance standard for assessing the hydromorphological features of rivers and is a recommended method for the agreed protocol for field survey and recording of morphological features²². RHS was also used to help develop and test the associated CEN guidance standard on determining the degree of modification on river hydromorphology^{6,23}. In the UK, RHS has been used for several Water Framework Directive (WFD)²⁴ purposes, helping to identify water bodies in 'reference condition', those classified as 'heavily modified' and also assessing morphological pressures affecting river catchments.

The STAR (STandardisation of River Classifications) project was a research initiative funded by the European Commission and was completed in 2005. The main aim was to provide standard biological assessment methods compatible with WFD requirements. It also set out to develop a standard for determining the class boundaries of 'ecological status' and another one for inter-calibrating existing methods. In Austria, The Czech Republic, Denmark, Germany and Italy 'core' RHS sites were chosen to reflect a gradient in habitat and morphology degradation. Results from the STAR project were published in a special issue of *Hydrobiologia* in 2006⁴.

Aquatic macrophyte surveys

Wherever possible, two macrophyte survey methods are used at benchmark RHS sites - for calibration purposes and an assessment of water quality. The JNCC method² records aquatic and marginal plants within the same 500m as the RHS survey. Species from the river channel and along the base of the bank are recorded separately on a three-point scale of abundance. A check-list of species is used for recording and to aid interpretation of results. Data are held on a JNCC database and used to classify the plant community². The MTR survey³ records only aquatic taxa, again using a check-list of species, but within a 100m length of river. Each species is assigned a trophic rank of 1-10, depending on its tolerance to eutrophication (1=tolerant; 10=intolerant). Cover abundance of species is estimated on



For JNCC macrophyte surveys, vegetation in the channel and along the margins is recorded.

a scale of one to nine and the combination of cover values and trophic rank enables a MTR score to be derived. This provides an indication of the level of nutrient enrichment in the sites surveyed.

The Makrofitowy Indeks Rzeczny (MIR) method is the Polish adaptation of MTR. Data collection is identical but the system uses some different species and alternative score weightings are used for selected taxa²⁵. Comparison of MTR and MIR results was made during previous survey work in Poland^{17, 20}.

Inter-calibration

For inter-calibration purposes, methods such as RHS and MTR that have been developed for rivers in the UK need to be tested and adapted for use elsewhere in Europe where hydrology, morphology, floristic and landscape character differ¹³⁻²⁰.

THE HIGH TATRAS - CHARACTER AND LAND-USE HISTORY

The High Tatras belong to the western part of the Carpathian mountain range and include its highest peak (Gerlachovský štít), at 2,655m. The mountain range straddles the Poland-Slovakia border and represents an extremely popular tourist destination for both winter skiing and summer hiking, attracting more than 3 million visitors each year. The main ridge is less than 30km long, with many peaks exceeding 2000m and the high mountain landscape rises abruptly from the surrounding basins. Tourism is the major economic activity and there are



Bryophytes and other plants growing in the channel are used to calculate MTR and MIR scores.

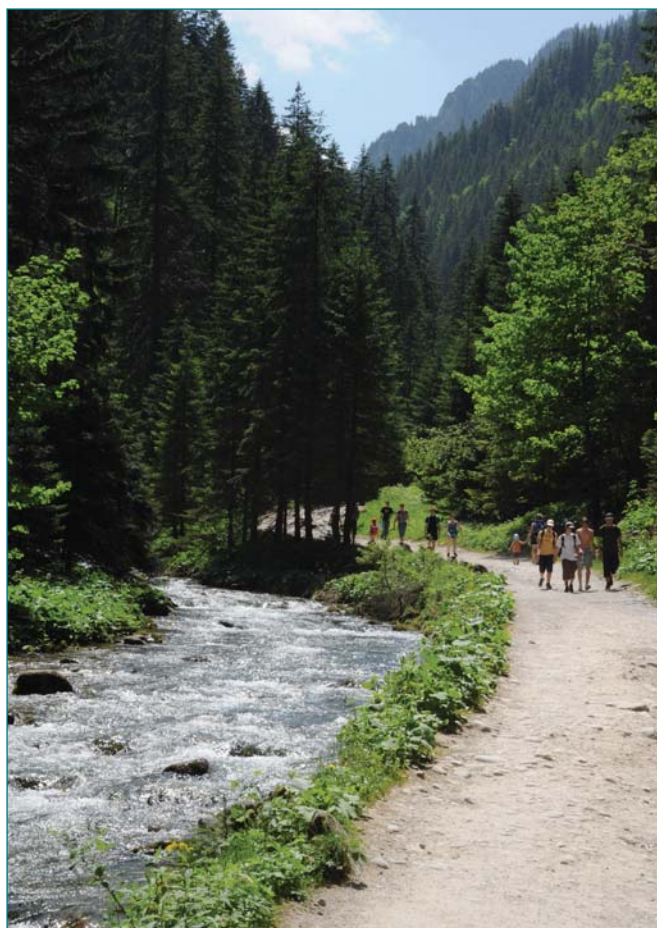


The High Tatras rise abruptly from surrounding plains.

several hundred kilometres of way-marked hiking trails and several cable cars to the high peaks. In Slovakia the mountain trails are closed from 1st November to 15th June for safety and wildlife protection reasons; in Poland they are open throughout the year except for three that are closed during December-May. In all cases, special permission is needed for access beyond the hiking trails.

Geology, landscape and climate

Geological structure determines landform and vegetation. Crystalline rock (mainly granodiorite, granite aplites, schists and migmatites) forms the core of the High Tatras. The area was glaciated or influenced by a peri-glacial climate, producing classical arêtes, cirques, tarns, scree slopes and moraine deposits.



Hiking trails are very popular in the summer.



Bielovodská dolina - a spectacular U-shaped glaciated valley.



Tarns are an attractive feature of the High Tatras.



Dwarf pine and alpine grassland occur above the natural tree-line.



Coniferous plantation forestry extends right to the water's edge.

There is a distinct vegetation zonation in the mountains. Between about 800m and 1250m the forests are dominated by spruce *Picea abies*. Spruce became predominant largely in the 19th /early 20th century as a result of clear-cutting and selective logging of native fir *Abies alba* and beech *Fagus sylvatica* to create a large plantation forest. In the two National Park areas (see below) this forest has subsequently been managed for nature conservation purposes. Between about 1250m and 1550m spruce occurs naturally, whilst between 1550m (the natural tree-line) and 1800m dwarf pine *Pinus mugo* and willow shrubs *Salix* spp. occur. Alpine grassland/dwarf shrub occurs between 1800m and 2300m above which the landscape is largely rock and scree.

Climatic conditions are extreme. Snow cover on the highest peaks lasts for 200 days a year, with some snowfields present all year. Precipitation exceeds 1500mm



Avalanche tracks are often colonised by dwarf pine and other native shrubs.

on several peaks, whilst local storms are frequent and unpredictable with high wind speeds. On 19th November 2004, a ferocious localised storm, with wind speeds up to 194km/h, destroyed 12,500ha of spruce forest between Podbanské and Tatranská Kotlina. Avalanches and rock-falls triggered by snow, frost and heavy rain are regular hazards in the winter.

National Parks

There are two adjacent national parks: the Tatranský Národný Park (TANAP) in Slovakia and Tatrzański Park Narodowy (TPN) in neighbouring Poland to the north. The TANAP was designated in 1949 and covers 73,800ha, with 30,703ha having the strictest protection. The Polish TNP was designated in 1955 and covers 21,164ha, of which 11,515ha is strictly protected. The TANAP and TNP together form the Tatras Biosphere Reserve, established by UNESCO in February 1993.

Land-use and wildlife

About 70% of land is forested; spruce is commercially exploited outside the strict nature protection areas, but is managed for conservation elsewhere. Today, there is little cultivation above 800m and no livestock grazing above the tree-line. Here, the only herbivores are chamois *Rupicapra rupicapra*, red deer *Cervus elaphus*, roe deer *Capreolus capreolus*, marmot *Marmota marmota latirostris* and voles, including snow vole *Chionomys nivalis*. Large carnivores such as wolves *Canis lupus*, brown bear *Ursus arctos* and lynx *Lynx lynx* inhabit the extensive forest tracts. On the Slovakian side infrastructure to support high recreational use is increasing.



Marmots are a feature of the High Tatras.



Bears were very elusive during our visit.

Channel modification

Streams in the valley floor, particularly near roads, forest tracks and settlements have armoured banks. These typically comprise tree trunks and boulders, but gabion baskets are also used as revetment. Boulder removal from the channel is also carried out. In extreme cases, particularly in villages, the channel is represented by a concrete trough. This modification pattern is typical of alpine and mountain areas across Europe. Our survey was therefore confined to high altitude, headwater streams to avoid artificial modifications to the channel.

Forestry management

Although the valleys have been extensively colonised and planted with spruce, there are areas in the strictly protected National Park zone where little or no commercial forestry operations (e.g. logging) have been carried out for the last 50 - 150 years. Here, natural woodland processes have been encouraged and as a result, mosses and lichens are luxuriant and an understorey of shrubs such as bilberry *Vaccinium myrtillus* has developed. In several places, particularly higher up the valley slopes, the plantation forest is therefore very gradually reverting to a more natural structure, helped by tree-thinning and allowing fallen trunks to decay. In some areas storm-damaged



Concrete banks-an extreme form of channel modification.



Re-profiled bank with wire basket gabions.



Tree trunk and boulder bank revetment.



Boulders removed from the stream-bed.

trunks have been removed, whilst in others the trees have been left alone and regeneration allowed to take place naturally. Bark beetles (mostly *Ips typographus*) damage and kill spruce trees, especially on the edges of storm-damaged areas and during warmer years. This has led to management conflict between foresters, who want to remove dead trees and replant with commercial spruce, and nature conservationists, who favour natural regeneration by secondary succession starting with broad-leaved trees such as rowan *Sorbus aucuparia*, birch *Betula* spp. and alder *Alnus glutinosa*. Major avalanche tracks with boulder-sized scree and vegetated with dwarf-pine penetrate the spruce forest and this pattern is clearly indicated on 1:25,000 scale maps and aerial photographs. Accounting for re-naturalisation of the plantation forest is a major topic in the Discussion section.

Wolves, lynx and bears were almost driven to extinction as a result of persecution in the early 20th century (1920s - 1930s), but following legal protection (1932) and the regulation of forestry and hunting since 1950s their populations have recovered even though the forest is still predominantly plantation-like or mid-successional in character.

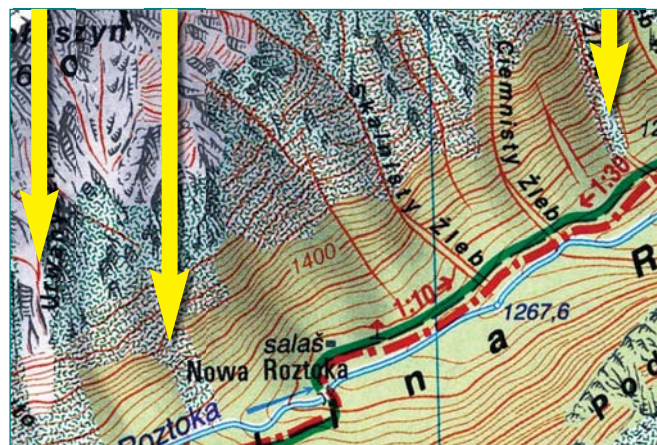
STUDY AREA

Our study area focused on the central part of the High Tatras. We selected four headwater valleys in a small (ca.10 x 10 km) geographical area to minimise travel-time from our base in Stará Lesná and because access to sites often involved a two-hour walk from the nearest road or track.

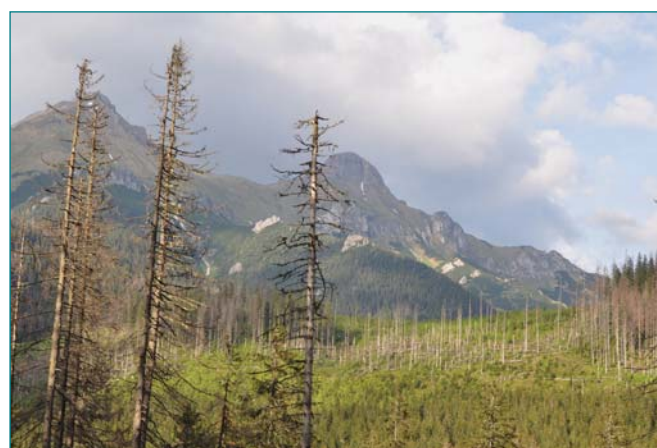
The four streams provided a representative range of altitude, gradient and land-use (Figure 1). Table 1 shows the type of land-use upstream from our sites.

1. The **Javorinka** typified a steep gradient stream in spruce forest in a catchment of mixed granite and limestone/quartzite geology.
2. The **Biela voda** flows parallel to and west of the Javorinka. Our 4km sequence descended through dwarf pine and spruce forest, with a distinctively different, low gradient reach in the middle.
3. The **Zadná Tichá** is in a west-facing catchment immediately west of the Potok Roztoka (see below) and provided a 1.5km sequence of sites in alpine grassland and dwarf pine landscape, as well as 1km in re-naturalising spruce forest below the tree-line.
4. The three **Potok Roztoka** sites were all above the tree-line, comprising the inflow to a large tarn (Wielki Staw Polski) and its outflow which tumbles down Poland's biggest cascade/waterfall (Siklawka).

The geology of the river catchments upstream from our survey sites on the Biela voda, Zadná Tichá and the Potok Roztoka is dominated by crystalline granitic rock, mostly biotite granodiorites. The upper Javorinka catchment has similar geology, but along our 2km survey length the geology is complicated by outcrops of crystalline massif, tectonic klippe, sub-tatric



1:25,000 scale map clearly showing avalanche tracks colonised with scrub.



Storm damaged plantation forest.

nappes and pelitic limestones²⁶. This difference in underlying geology was reflected in the aquatic macrophyte communities we found.

On 12 June we also made some incidental observations walking along the **Kościeliski Potok** which flows in a limestone gorge located about 10 km south-west of Zakopane. This was to compare macrophyte communities here with the streams in our main study area. Incidental wildlife sightings were recorded during our visit because they provide useful additional information (Annex L).

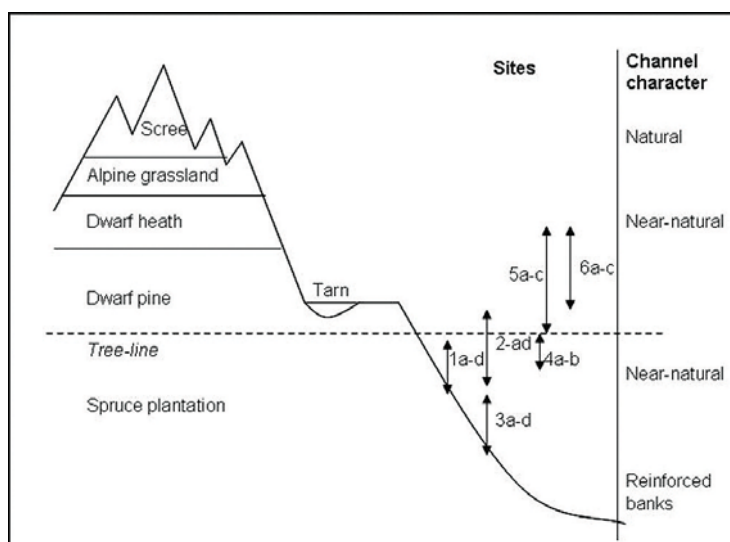
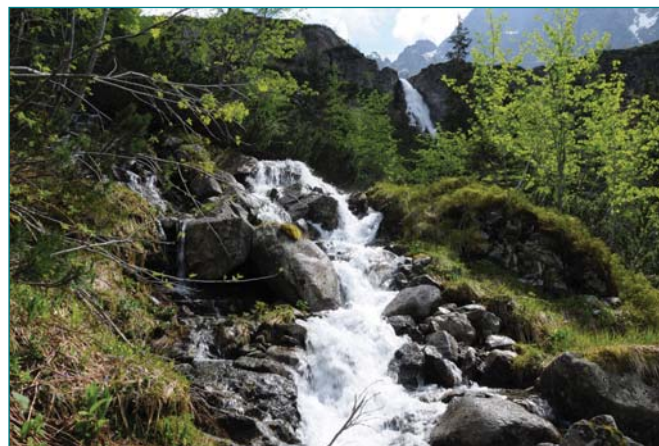


Figure 1. Schematic cross-section of the High Tatras, showing the position of our survey sites.



The Javorinka.



The Biela voda near its source.



A bedrock cascade on the upper Zadná Tichá.



Tributary of the Potok Rostoka.



The Kościeliski Potok flows through a limestone gorge.



Map butterfly, Kościeliski Potok.

TABLE 1: Catchment land-use upstream from study sites.

River	Percentage of upstream catchment area					Catchment Area (km ²)
	Forestry	Dwarf pine	Rock/scree	Alpine meadow	Other	
Javorinka	9.3	18.0	52.2	9.5	11.0	10.8
Biela voda	10.5	12.6	45.8	17.2	13.9	15.4
Zadná Tichá	5.5	22.6	5.1	48.4	18.4	4.2
Potok Rostoka	15.9	21.8	50.8	7.4	4.1	13.3



Higher discharge on the Biela voda at Lysá pol'ana on the 5th June (left) compared to the 12th June (right).

SURVEY AND ASSESSMENT

Study sites and conditions during survey work

The location of sites we surveyed is shown on the back cover of the report and in more detail in Annex A. We completed 19 RHS surveys during 6 – 11 June 2010. Our survey occurred the week before the opening of the paths to hikers in Slovakia and we had special permission to work along the streams – a great advantage for undisturbed conditions. The weather was fine and sunny throughout. However, snowmelt, plus one month of persistent heavy rainfall in May (which caused extensive flooding in parts of Poland, Hungary and Slovakia) meant that water levels were elevated. Higher than normal discharge inevitably affected the observed flow-types; for example unbroken standing waves in low-flow conditions becomes broken standing waves in higher discharges. However, the high discharge and snowmelt enabled us to survey the headwaters of the Zadná Tichá and Potok Roztoka in prime condition.

River Habitat Survey

All RHS surveys were undertaken by Paul Raven, with assistance from Hugh Dawson (Tatra 3a-d; 4a-b; 5a,b) Agnieszka Ławniczak and Marta Szwabińska (both Tatra 6c). Four consecutive sites (2km) were surveyed on the Javorinka, eight on the Biela voda (4km) and a set of three (1.5km) and two sites (1km) on the Zadná Tichá. One pair (1km) and a single site (500m) on the Potok Roztoka were located upstream and downstream of the Wielki Staw Polski tarn respectively. By completing several double and multiple surveys we maximised the use of our survey time and could also determine the variation in number and type of features recorded over different lengths of river.

Calculation of HQA and HMS scores was based on the 2005 version (2.1) of these systems – with HQA adapted for local conditions in similar fashion to sites surveyed in Slovenia, the Bavarian and the Tyrolean Alps, the Cévennes, Poland, Picos de Europa and southern Portugal¹⁴⁻²⁰. As before, several assumptions were made about the inclusion and scoring of special features and 'near-natural' land-use. Additional special features and generous interpretation of semi-natural land-use mean that HQA scores can be 10 points or more than those automatically generated using the UK scoring system. The effect of this was illustrated for the River Drawa²⁰. The suggested scoring protocol used for HQA calculation for re-naturalising spruce plantation forest in the High Tatras is shown in Table 6.

A complete set of RHS survey forms, a CD-ROM with digital photographs, maps showing locations, sketches and comprehensive macrophyte lists for each site are available on request. Site numbers, prefixed with "Tatra" are unique codes that identify individual survey sites. These are in chronological order based on survey date (1a-d; 2a-d etc). Results are presented in upstream-downstream order, meaning that the chronology is altered for the Zadná Tichá (5c, a, b; 4a, b is the downstream sequence) and Potok Roztoka (6b, a, c).

Information needed for PCA plots, (such as height and distance from source) was derived from the Vysoké Tatry 1:25,000 scale topographic map in the *Podobná Turistická Mapa* series. The 10m contours and water-level spot heights marked on these maps were used to calculate channel slope (gradient) and site altitude. Surface geology was determined from a schematic map of the Tatras (Szczegółowa mapa geologiczna Tatr w skali 1:10,000 scale) and from the 1:50,000 scale geological map of the area²⁶.

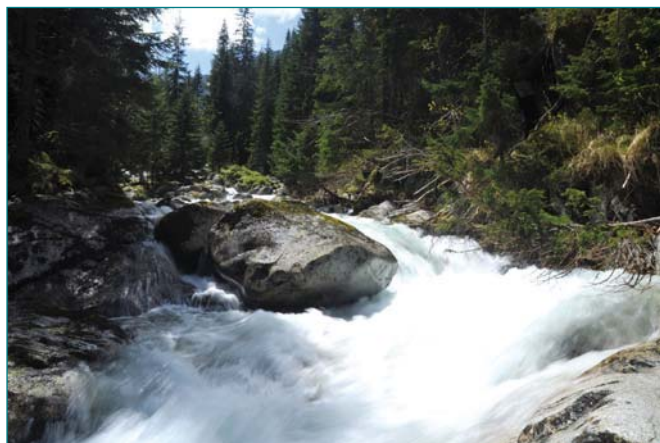
Aquatic macrophytes and water chemistry

Nigel Holmes carried out the macrophyte surveys, using JNCC² and MTR methods³ at all 19 RHS sites (Annex F, G). MIR results were calculated by Agnieszka Ławniczak for comparison with MTR scores²⁵. MIR samples were taken from the 100m section between spot-checks 6 and 8, in line with the STAR protocol⁴. Nomenclature for the common names of those liverworts and mosses found in Britain and Ireland is based on the British Bryological Society field guide²⁷.

Water samples collected by Hugh Dawson were stored in full sealed containers and analysed in the NERC laboratory (Wallingford, UK) within 20 days, using fully calibrated equipment (Annex H).

Benthic macroinvertebrates

Benthic macroinvertebrates were collected by Iga Lewin using a square-framed hand-net (25x25cm) with 500µm mesh-size. Representative samples comprising 20 replicates from all the major microhabitats present were collected^{28,29}. In addition, 20 core samples (diameter 50mm) were also taken to collect oligochaetes and chironomids living deeper in the sediment. Material was preserved in 75% ethanol for later identification in the laboratory. Core samples were sieved with a 0.23mm mesh net before sorting. Identification was to family or genus level as



Boulders and white-water, Javorinka.



Forest clearing, created by an avalanche, Javorinka.

required by the BMWP(PL) method^{28,29}. Samples were taken from the Biela voda (Tatra 2d/3a), the main tributary of the Potok Roztoka (Tatra 6b) and both upstream and downstream of the Siklawka waterfall on the Potok Roztoka (Tatra 6c) (Annex I). These contribute to an extensive survey of benthic macroinvertebrates in Poland.

European guidance standard on hydromorphological modification

The European (CEN) guidance standard⁶ on hydromorphological modification is based on a set of attributes and an associated scoring protocol that assess departure from near-natural conditions within a given reach. The attributes are scored on a 1-5 scale, with 1 representing near-natural conditions and 5 reflecting a severely modified state. A 1* classification is achieved when the attribute is considered to be in pristine, or near-pristine condition. Some attributes are assessed quantitatively and others qualitatively (Annex J). Various sources of data derived from aerial photographs, maps and field surveys such as RHS can be used to score relevant attributes separately in a quantitative or semi-quantitative manner, with the overall score for a reach calculated using the best available information relevant for assessment purposes. This allows for broad comparisons of reaches along and between rivers to be made. For example, we previously compared the near-natural conditions of the Drawa River in north-west Poland with the River Itchen, a much more modified river of similar hydrological character in southern England²⁰.

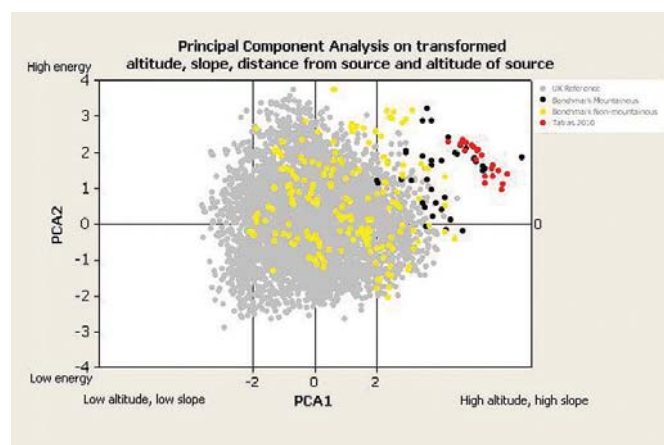


Figure 2. PCA plot, showing the Tatra sites (red) compared with high altitude (black), other benchmark sites (yellow) and the UK baseline survey sites (grey).

RESULTS

Context in relation to European hydro-ecoregions and UK rivers

Figure 2 shows the PCA plot of the High Tatra sites, compared with previous European benchmark surveys¹⁴⁻²⁰ and the 1994-1996 stratified random baseline network of sites in the UK⁷. All other benchmark sites located above 600m are shown in black, which illustrates the very high altitude of our study area located in the 'Inner Carpathians' hydro-ecoregion³⁰. This is in the same 'crystalline middle mountain' hydro-ecoregion grouping as the Cévennes in south-east France and the Scottish Highlands visited in previous benchmarking survey work³.

River landscape character

Javorinka

The Javorinka rises at 2010m at the head of a deeply glaciated valley, (Zadná Javorová dolina), and flows north towards Tatranská Javorina. Near the source there is a small tarn (Žabie Javorové pleso) at 1878m altitude. The Med'odolský potok forms a significant right bank tributary. Our 2km long study reach (3.25-5.25km from source) was a boulder-strewn channel, dominated by chute and broken wave (white-water) flow. It included a notable waterfall



Litvorový potok, a tributary of the Biela voda.

and a significant right bank tributary, the Čierny potok. The spruce forest was even-aged but in places the structure was more open, with a bilberry understory, luxuriant bryophyte flora and occasional mountain ash growing along the channel edge. A spectacular forest clearing created by avalanches was a prominent feature near the upstream end. At the downstream end, gigantic inter-locking boulders alongside the channel have created ideal dens for bears.

Biela voda

The Biela voda rises in a glacial cirque below the imposing peak of Zadný Gerlachovský štít (2606m). It then flows virtually due north within a spectacular glacial valley (Bielovodská dolina) located parallel to and 2-3km west of the Javorinka. Access and safety concerns prevented us surveying the uppermost part of the Biela voda where it forms an attractive waterfall downstream from a small tarn, the Zelené pleso Kačacie. We therefore started our survey on the Litvorový potok, a tributary stream that flows into the Biela voda 400m downstream from our starting point.

The first 1000m of our survey was dominated by a boulder-bed torrent cascading initially through dwarf pine, then spruce plantation. A marked break in slope then produced a significant change in stream habitat, including a 400m length of much gentler gradient (5-10m/km) channel, characterised by riffles, point bars, backwaters and side channels. After that, the slope increased, producing a boulder-strewn channel once again.

Dense dwarf pine growth dominated the landscape above about 1500m altitude. Below this was re-naturalising spruce plantation. In several parts the forest was relatively open, with bilberry, abundant bryophytes, decaying fallen trees and occasional mountain ash along the channel edge. Rock-falls and avalanches had evidently sent massive boulders into the channel, whilst hardwood trees and dwarf pine were growing on more stable parts of the valley scree. The plantation-like character of the spruce forest intensified downstream.

Zadná Tichá

The Zadná Tichá rises at the head of a glacial valley, flowing west then south in a heavily forested landscape. The Tichá dolina is well-known for its nature conservation interest³¹.

We surveyed three consecutive sites (Tatra 5c-5a in downstream sequence) near the source (1890m), in alpine grassland and dwarf pine landscape. About 1km further downstream we surveyed two sites (Tatra 4a, b) where the stream flows through spruce forest which is gradually re-naturalising. At the extreme downstream end hundreds



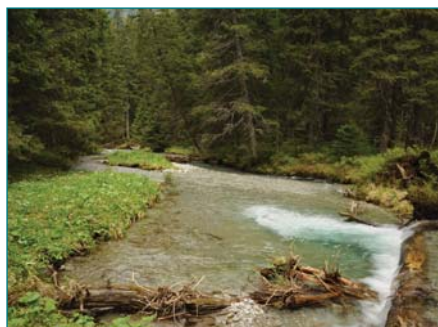
Bedrock chute, upper Zadná Tichá.

of fallen spruce trunks have deliberately been left where they fell during the storm of November 2004. Dozens lie across the channel, forming debris dams and creating temporary pools.

Potok Roztoka

The Potok Roztoka rises in a large north-east facing cirque below a 2000-2200m high semi-circular ridge. The alpine landscape is dominated by dwarf pine, *Nardus* grassland and flushes. Our study focused on the main inflow and outflow of Wielki Staw Polski, the largest of four tarns in the area. The cobble-bed stream rises at 1870m and cuts through moraine terraces, entering the tarn at 1664m altitude. We completed two RHS sites (1km) here.

Immediately below the Wielki Staw Polski tarn, the Potok Roztoka is dominated by Siklawka, the highest (70m) waterfall/cascade in Poland and this feature was located in our single 500m survey. Rock, scree and dwarf pine



Gentle gradient middle reach of the Biela voda.



Storm-damaged spruce trees, Zadná Tichá.



Moraine terraces alongside the Potok Roztoka.



Siklawka waterfall, Potok Roztoka.



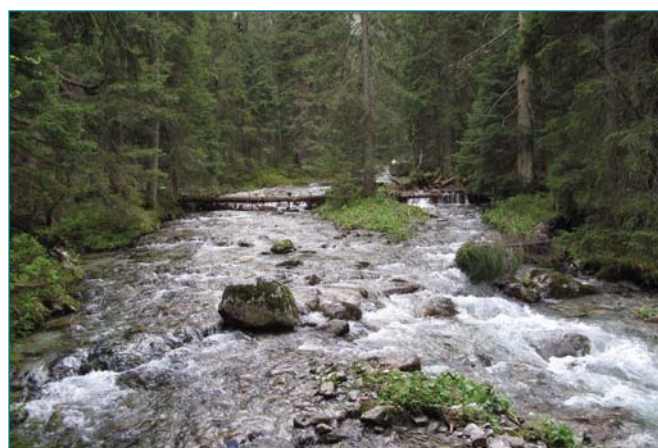
'Rapid' stream-flow, Biela voda.

dominate the landscape, contrasting with the spruce forest further downstream where the river valley is very similar in character to the Javorinka and also the Biela voda.

Morphological character

All four of our study streams had boulder or cobble beds, with bedrock gulleys and small canyons in the steepest parts. Table 2 summarises the main habitat features of each, with Appendix 1 and Annexes B-D containing more detailed information and the HQA and HMS scores. Since channel gradient is the primary determining factor for flow-type, substrata and channel features, sites can be classified on their overall stream-flow character, based on the predominant flow-types found at spot-checks¹³. On this basis there were 16 'rapid' and 4 'rapid-moderate' sites in our survey. A broadly similar range of features was found in all the sites, with local changes in channel slope strongly influencing the occurrence of specific features. The much gentler channel slope in Tatra 2d/3a on the Biela voda demonstrates this effect well, with point bars and riffles occurring.

HQA sub-scores reflect the variety of flow-types, in-channel features and sparse aquatic vegetation throughout. Bank vegetation structure, tree features and land-use were strongly influenced by site location within or above the



'Rapid-moderate' stream-flow, Biela voda.

spruce plantation forest. The highest HQA score was associated with the very diverse riparian habitat in the gentle-gradient part of the Biela voda where the channel splits into two (Appendix 1; Annex B, C).

TABLE 2: The occurrence of selected habitat features in 'rapid' and 'rapid-moderate' stream-flow character reaches.
Bold text highlights notable differences.

River	Javorinka	Biela voda		Zadná Tichá	Potok Roztoka	
Stream-flow character <i>site number</i>	Rapid (1a-d)	Rapid (2a-c;3b-d)	Rapid-moderate (2d,3a)	Rapid (4a,b;5a-c)	Rapid (6c)	Rapid-moderate (6a,b)
Waterfalls	Present	Present	None	Present	Extensive	None
Exposed boulders	Extensive	Extensive	Extensive	Extensive	Present	Extensive
Vegetated boulder/bedrock	Present	Present	Present	Present	Absent	Present
Unvegetated mid-channel bars	Present	Present	Present	Present	Present	Present
Vegetated mid-channel bars	Present	Present	Present	Present	Absent	Present
Mature islands	Present	Extensive	Extensive	Present	Absent	Present
Unvegetated side bars	Present	Present	Present	Present	Present	Absent
Vegetated side bars	Present	Present	Present	Present	Absent	Present
Unvegetated point bars	None	None	Present	Present	None	None
Vegetated point bars	None	None	Present	None	None	None
Natural berm/terrace	None	None	Extensive	Present	None	Extensive
Riffles (<i>number</i>)	None	None	Present (2-7)	None	None	None
Pools (<i>number</i>)	Present (1-7)	Present (0-4)	Present (0-4)	Present (7-18)	Present (5)	Present (1-2)
HQA score (range)	63-66	58-69	73-87	53-76	59	51-55

Cumulative occurrence of features

The cumulative occurrence of features in consecutive RHS sites is a useful way of determining the best sampling intensity for rivers with similar stream-flow character¹³. Table 3 shows the number of predominant channel substrata, flow-types and channel and bank features found in each RHS site recorded on the Javorinka ($n=4$), Biela voda ($n=8$), Zadná Tichá ($n=3$; 2) and Potok Roztoka ($n=2$). The downstream appearance of new features in consecutive sites is expressed as cumulative percentage of the sequence as a whole.

Three or more consecutive sites with ‘rapid’ stream-flow character occurred in four sequences; the Javorinka (Tatra 1a-d), the Biela voda (Tatra 2a-c; 3b-d) and the Zadná Tichá (Tatra 5c-a). In each case at least 83% of total features recorded occurred in the first two sites (1km).

The ‘rapid-moderate’ stream-flow reach mid-way along the Biela voda survey meant that new features suddenly made an appearance and this inevitably affected the cumulative profile. Nevertheless 96% of features of the Biela voda were recorded in the first four sites (i.e. 2km), regardless of the change in stream-flow character.

Percentage accumulation figures for ‘rapid-moderate’ stream-flow character on the Biela voda and Potok Roztoka are restricted to two consecutive sites alone. This means the results are less conclusive, but in each case (Tatra 2d,3a; Tatra 6b,6a), 83% of total features recorded occurred in the first site (500m). Nevertheless the pattern is very similar to that found elsewhere for consecutive RHS sites on near-natural streams and rivers, reaffirming the conclusion that for benchmarking purposes two or more RHS sites should be carried out wherever possible¹³.

TABLE 3: The number of different flow-types, predominant channel substrata and habitat features in consecutive RHS sites, showing the cumulative appearance of new features. Stream-flow character: R = rapid; R-M = rapid-moderate. *Over-ride applied to 5a (rapid stream-flow type).

River	Javorinka				Biela voda								Zadná Tichá					Potok Roztoka		
Site number, in downstream sequence	1a	1b	1c	1d	2a	2b	2c	2d	3a	3b	3c	3d	5c	5b	5a	4a	4b	6b	6a	6c
Stream-flow character	R	R	R	R	R	R	R	R-M	R-M	R	R	R	R	R	R*	R	R	R-M	R-M	R
Predominant channel substrata	4	4	2	3	3	4	3	3	3	3	2	3	3	4	4	3	3	3	3	3
Flow-types	6	7	7	7	6	7	6	5	6	6	5	6	7	6	7	7	6	6	6	5
Channel and bank features	9	10	10	10	10	9	9	12	15	11	12	11	7	10	3	8	11	6	7	6
Total per site	19	21	19	20	19	20	18	20	24	20	19	20	17	20	24	18	20	15	16	14
Cumulative total	19	21	23	23	19	21	23	27	28	28	28	28	17	20	24	18	24	15	18	-
Percentage accumulation (within-type)	83	91	100	100	83	92	100	83	100	87	100	100	71	83	100	75	100	83	100	-
Percentage accumulation (all types)	-	-	-	-	68	75	82	96	100	100	100	100	-	-	-	-	-	-	-	-
Channel gradient (m/km)	110	90	80	70	380	180	34	12	30	100	50	40	200	260	170	190	80	80	90	280

The occurrence of features in adjacent sites

Comparing the occurrence of features in adjacent RHS sites is another way of assessing variation in river character. Results are affected by the number of sites involved and changes in stream-flow character, but they provide a reasonable indicator of the probability of features occurring over different survey lengths. Our study area provided ten pairs of ‘rapid’ stream-flow sites and two pairs of ‘rapid-moderate’ sites. Comparison with the occurrence of features in other paired benchmark sites of ‘rapid’ stream-flow character is presented in Table 4. In addition, comparison of features recorded in single benchmark sites of ‘rapid’ and ‘rapid-moderate’ stream-flow character appears in Annex E. Taken together, the overall pattern

suggests that our High Tatra sites have more vegetated boulders, mid-channel bars and side bars than similar streams elsewhere (e.g. the Picos de Europa streams, where sediment supply is limited by the limestone nature of the geology¹⁸). There was also a higher occurrence of natural terraces and discrete sand deposits, with correspondingly fewer unvegetated side bars and marginal deadwater areas. This might appear surprising, but one possible explanation is that sufficient stability is provided by finer (gravel/sand) material that accumulates between or downstream of very large boulders and cobbles entering the channel from avalanches and rock-falls. Also, in prolonged dry periods in late summer the margins and in some cases entire lengths of headwater streams may occasionally dry out, allowing plants to colonise and stabilise the sediment.



Mature island, Biela voda.



Point bar and riffle, Biela voda.

TABLE 4: Percentage of flow-types, channel substrata and channel features occurring in adjacent RHS sites of 'rapid' stream-flow character: a comparison of High Tatra and other benchmark sites. Bold type indicates notable differences.

	High Tatra sites		Other benchmark sites	
	%	<i>n</i>	%	<i>n</i>
Flow-type				
Free-fall	60	10	100	6
Chute	100	10	100	6
Broken wave	100	10	100	6
Unbroken wave	100	10	100	4
Rippled	100	10	100	6
Upwelling	100	10	100	6
Marginal deadwater	50	8	100	6
Predominant channel substrata				
Bedrock	50	6	75	4
Boulder	100	10	100	6
Cobble	80	10	80	5
Gravel-pebble	70	10	75	4
Features				
Exposed bedrock	75	8	75	4
Exposed boulders	100	10	100	6
Vegetated boulders/bedrock	60	10	33	3
Unvegetated mid-channel bars	90	10	100	3
Vegetated mid-channel bars	60	10	0	2
Mature islands	77	9	75	3
Unvegetated side bars	62	8	100	5
Vegetated side bars	88	9	66	3
Unvegetated point bars	0	1	100	1
Vegetated point bars	0	1	0	1
Natural berm	0	2	-	-
Natural terrace	33	3	-	-
Pools	90	10	84	6
Discrete sand deposit	84	6	-	-
Discrete gravel deposit	100	10	100	3
Discrete cobble deposit	66	9	-	-



Vegetated mid-channel bars, tributary of the Potok Roztoka.



Natural berm/terrace formation, Biela voda.



Very low flow in the Javorinka, October 2010.



Afforested channel, Javorinka.

Morphological assessment using the CEN guidance standard

Annex K shows the results for all the RHS sites individually and as reaches. Because we targeted headwaters in mountainous landscapes to avoid channel modifications lower down the valleys (Figure 1), the CEN scores would be expected to reflect near-natural hydromorphological conditions. Most of the High Tatra sites and reaches were assigned 1* status for the majority of attributes, which reflected the natural plan-form, stream-bed and, where the valley floor allows (e.g. Biela voda in Tatra 2d/3a; Potok Roztoka in Tatra 6a/b), lateral movement of the channel. Although aquatic macrophyte vegetation is sparse, it is clearly not managed.



Picture postcard view of the Biela voda.

The main departure from 'naturalness' (defined by CEN attributes 8 and 9) is the lack of genuinely natural bank and riparian vegetation (Annex K). This is because either grazing or afforestation occurred right up to the river edge and insufficient natural recovery has taken place, despite several decades without sheep/cattle grazing or commercial forestry operations. With the exception of the Potok Roztoka, a 1* score was not achieved for large woody debris because the material comprised plantation spruce trees, not native wild-wood species.

Despite this, the streams with their spectacular mountain backdrop and dense forest provide wonderful picture postcard views and an obvious attraction for hikers.



Spruce trunk debris dam, Javorinka.

The effect of increasing bank protection and other measures to protect tracks and roadways from erosion downstream from our study sites is clearly demonstrated by the CEN scores for the Biela voda. Below a point about 2km downstream from Tatra 3d the Biela voda flows in a much wider valley floor and the banks are reinforced variously with logs, boulders and wire gabions. Cobbles are also removed from the river bed to speed the flow. Annex K illustrates the difference between the 4km RHS survey stretch (Tatra 2a-3d) considered alone and in combination with a further 8km of the channel downstream to Lysá pol'ana, the features along which were seen whilst travelling to and from the RHS sites.

Aquatic macrophytes

At most sites there were no higher plant aquatic species (Annex F, G). Of all the taxa on the UK's MTR check-list,



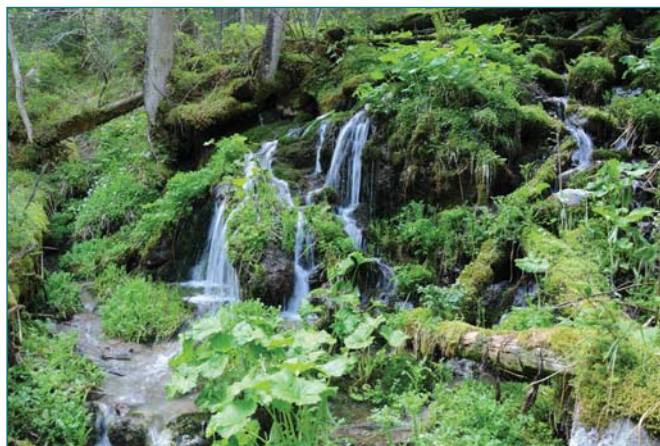
Bank reinforcement on the Biela voda downstream of our survey sites.

bryophytes were the only species recorded at all the sites surveyed. Several bryophyte species were ubiquitous, but rarely common. These included water earwort *Scapania undulata*, sharp-leaved Blindia *Blindia acuta*, rusty feather-moss *Brachythecium plumosum*, marsh Bryum *Bryum pseudotriquetrum* and transparent fork-moss *Dichodontium pellucidum*. Bryophytes also were dominant on the banks; higher plants were only present further up the bank except where gravel bars were present or where flushes extended down to the channel. The diversity of species within the channel was limited, and the cover very sparse, caused by the extremely harsh environmental conditions. Many of the bryophytes exhibited atypical form, presumably due to the effects of extreme flow ranging from spates to drying and extended periods under deep snow and ice in the winter.

The macrophyte communities in the Biela voda differed little from other sites with the exception of the gentle gradient section (Tatra 2d-3a) where the channel splits into two. Here, in the more sluggish back-channel, greater water-moss *Fontinalis antipyretica* was common on tree roots and embedded boulders, with bog-mosses *Sphagnum* sp.(p.) common along the swampy margins. The MTR score in the back-channel was 80, even though water chemistry was the same as the main channel (MTR = 91). The reason for the lower score is simply due to the habitat-related taxa differences; *Fontinalis* (a lower scoring species) can grow in the sluggish back-channel but not in the fast-flowing main channel. This difference has important implications for MTR sampling strategy and interpretation. Annex F shows that water quality assessment using the MTR and MIR scoring protocols on the recorded bryophytes produced almost identical results.



In-channel bryophytes are very sparse.



A vigorous flush forming a waterfall.



A typical wet flush with *Caltha palustris* and *Equisetum fluviatile*.

Flushes

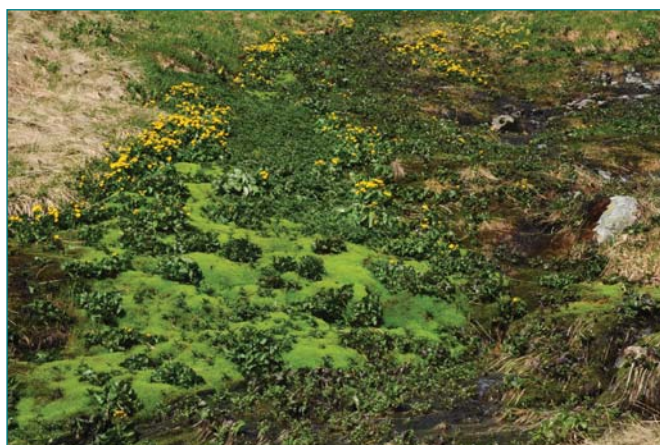
Extensive flush habitats occurred in the valleys. Their number, variety and extent were far greater than in any other benchmark sites we have previously visited. For example, in the Picos de Europa¹⁸, flushes tended to be small and predominantly close to the stream margins. In the High Tatras many valley sides were characterised by flush habitats extending well beyond the stream edge. They varied in character from discrete springs and rivulets in steep, rocky terrain to wide, peaty swamps with upwelling springs on gentler valley slopes. The commonest types were dominated by bryophytes interspersed with flowering plants such as marsh marigold *Caltha palustris*.

Common taxa included fountain apple-moss *Philonotis fontana*, dotted thyme-moss *Rhizomnium punctatum* and transparent fork-moss *Dichodontium pellucidum*. The more

acidic flushes had the attractive marsh forklet-moss *Dichodontium palustris* growing alongside overleaf *Pellia epiphylla*, earworts *Scapania* spp. and common haircap *Polytrichum commune*. More base-rich flushes had abundant claw-leaved hook-moss *Palustriella falcata* and curled hook-moss *P. commutata* dominant, growing alongside endive *Pellia endiviifolia*. Marsh marigold was the most widespread flowering plant in flushes; less common, but widespread species included alpine violet *Viola biflora*, false helleborine *Veratrum album*, the brassica *Arabis soyeri* subsp. *subcoriacea* and lousewort *Pedicularis* spp. A close relative of watercress *Cardamine amara* subsp. *opicii*, occurred in the most base-rich flushes, whilst the most water-logged ones often also featured the pteridophyte water horsetail *Equisetum fluviatile*. Cowslip *Primula elatior* and Carpathian snowbell *Soldanella carpatica* were also common components of flush communities, but usually these were more prevalent at the damper stream margins.



Two contrasting calcareous flushes with mixed bryophyte and higher plant communities.



A swampy flush dominated by the moss *Dichodontium palustris*.



Flush dominated by the moss *Plagiomnium* sp(p.) and *Arabis soyeri*.

Endemic plants

Several taxa that were characteristic of the flushes, but also locally common along the stream margins are rare on a global scale, with some endemic to the Carpathians and surrounding areas³³. Endemics included Carpathian

snowbell *Soldanella carpatica*, butterbur *Petasites kablikianus*, the brassica *Cardamine amara* subsp. *opicii* and toothwort *Dentaria glandulosa*.



Dentaria glandulosa (Carpathian sub-endemic).



Cardamine amara subsp. *opicii* (Carpathian-Hercynian taxon).



Petasites kablikianus (Carpathian-Hercynian-Illyrian taxon).



Primula minima (Low risk, near threatened taxon).



Dactylorhiza majalis (Vulnerable taxon in Slovakia).



Pinquicula alpina (Vulnerable taxon in Slovakia).



Soldanella carpatica (west-Carpathian endemic).



Pristine snow-melt water, upper Zadná Tichá.



Only bryophytes were used to calculate MTR scores.

Water chemistry and water quality

Water is pure in these high altitude streams. The snowmelt influence was high, producing very low conductivity ($12-28 \mu\text{Scm}^{-1}$), with major ions present at either trace or non-detectable levels (Annex H). Given the very low level of ions, pH measurements were unreliable, but field values of 6-6.5 were typical, reflecting the predominantly crystalline geology.

The MTR method uses macrophyte communities to assess the nutrient status of the water³. Scores of 80 or more indicate extremely low levels of nutrients. The High Tatra sites had consistently greater MTR scores (78-94; average 91.6) than previous benchmark surveys, suggesting extremely pure and nutrient-poor water. Despite only bryophytes being recorded, our confidence in making this assessment is high because MTR scores were based on an average of 10 or more taxa, with only one site having just seven taxa (Annex F).

TABLE 5: Summary of the benthic macroinvertebrate survey results.

Measure	Biela voda(Tatra site)		Potok Roztoka (Tatra site)			
	(2d)	(3a)	Tributary (6b)	Tributary (6b)	Upstream Siklawa (6c)	Downstream Siklawa (6c)
Number of taxa (families)	12	6	6	7	12	10
BMWP(PL) index	71	32	32	40	64	58
% Ephemeroptera, Plecoptera, Trichoptera	3.27	1.81	10.7	11.27	20.57	8.41
Average Score Per Taxon	5.92	5.33	5.33	5.71	5.33	5.8

Benthic macroinvertebrates

Very few taxa were recorded ($n=6-12$) and the samples were dominated by oligochaetes, chironomids and simuliids (Annex I). The first two groups of taxa are very tolerant of organic pollution and therefore the BMWP(PL) index and Average Score Per Taxon (ASPT) were both relatively low for our study sites, suggesting a potential water quality problem (Table 5). However, the absence of any obvious sources of organic pollution and the pristine nature of the water indicated by water chemistry and aquatic macrophyte results (Annexes F-H) suggest that the high altitude and extreme conditions in these headwaters (particularly the tributary of the Potok Roztoka) provide a more likely explanation for the very limited variety of benthic macroinvertebrates found.

DISCUSSION

Land-use history

Establishing whether land-use within 50m of the river channel and in the wider catchment is 'near-natural' can be difficult. Native broad-leaf and coniferous woodland/forest, wetland, and rock/scree are 'near-natural'



Scree slope colonised by dwarf pine.



Lightly managed forest, Scandinavia.



Even-aged beech woodland, Picos de Europa, Spain.

land-use categories in the current HQA scoring protocol^{7,12}. If, individually or collectively, these represent the only land-use categories within 50m of the river the HQA land-use score is 7 (i.e. near-natural land-use along both banks will score a maximum 14). The need to verify assumptions by taking land-use history into account has been highlighted in previous reports, as has the need for better diagnostic features to help improve field observations¹⁸⁻²⁰. A good example is that across the UK and much of western and central Europe 'near-natural' woodland and forest is not primary at all, but secondary and usually managed to some extent. We have encountered several examples – such as coniferous forest in Scandinavia and beech woodland in the Picos de Europa¹⁸.

Vertical land-use zonation in the High Tatras provided an ideal test (Figure 1). We assumed that the only truly near-natural vegetation occurred above the tree-line (c. 1500m), where the alpine grassland, dwarf heath, dwarf pine and wetland (flushes) were not grazed by livestock (sheep, goats), presumably because of bears,

wolves and lynx. However, palynological and archaeobotanical evidence, plus knowledge of historical land-use changes indicate that alpine grassland and dwarf shrubs in the mountains were grazed by sheep and cattle at least during the 16th – 19th century³³; consequently, most of the dwarf pine scrub is not primary, but a successional colonisation of abandoned alpine pastures and land that had been occasionally burned³⁴. Livestock grazing in the sub-alpine zone was abandoned from the late 1940s-early 1950s following designation of the Tatra National Park. Since then, grazing pressure above the tree-line has been largely limited to chamois, marmot, red deer, roe deer and voles, with these grazer numbers controlled by predators.

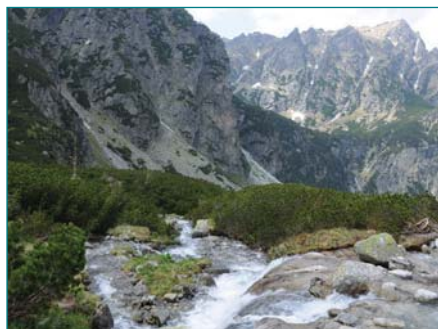
The original hardwood/mixed coniferous forest in most of the mountain valleys was repeatedly clear-felled, selectively logged or burned for several centuries - in some valley floors, from the Bronze Age - and replaced by spruce³⁴. In the National Park large areas are now in various stages of secondary succession or assisted re-naturalisation. Avalanche tracks and storm-damaged plantation forest are often colonised by a mixture of early successional trees and shrubs, such as mountain ash (dominant), birch *Betula pendula*, willows *Salix silesiaca* and dwarf pine. This provides clear evidence that natural processes could eventually produce a more natural forest structure and community, with less spruce and a more diverse understorey. Because they maintain natural disturbance regimes, support near-natural vegetation and facilitate



Native Caledonian forest, Scottish highlands.



Dwarf pine, alpine grassland and dwarf heath, Tichá dolina.



Dwarf pine, Litvorový potok.



Avalanches are an important source of boulders entering the channel.



Closed, even-aged plantation forest.

dispersal and migration, we have recommended that 'avalanche tracks' and 'unmanaged wind-throw' are specifically included as special features in the HQA scoring protocol (Appendix 2).

For RHS survey purposes, we recorded the spruce forest below the natural tree-line as "coniferous plantation" (CP), land-use, but recognised that some parts were re-naturalising. To account for this, we have suggested some criteria that could be used in HQA scores, based on features such as structure and the presence of fallen and decaying

trunks (Table 6). Using photographs to verify our assumptions during the survey, this scoring protocol has been used for HQA calculation in the High Tatra sites. Local knowledge of woodland management is invaluable in helping data analysis and the interpretation of results. The criteria in Table 6 should be tested, refined and adapted for use elsewhere.

Conversely, the current HQA scoring for trees and associated features is the same for native woodland and plantation forest. For ecological reasons, it would be useful

TABLE 6: Suggested attributes and HQA scores for re-naturalising coniferous plantation forest.

Forest structure and character	Proposed HQA score	
	Present	Extensive
Closed; even-aged. Dense trees, little light, no understorey.	0	0
Closed; even-aged. Thinned trees, sparse understorey.	0	0
Open; even-aged. <i>Vaccinium</i> understorey.	0	1
Open; even-aged. <i>Vaccinium</i> understorey, decaying fallen trees.	1	1
Open; multi-aged, patchy. <i>Vaccinium</i> understorey, fallen trunks, broadleaf trees present.	1	2
[Areas of unmanaged windthrow/bark beetle damage, patchy. Dead wood, broadleaf trees, tall herbs].	1	2
[Areas of avalanche/scree. Open. Dwarf pine and broadleaf species].	1	2



Even-aged forest, open structure, with bilberry.



Initial branch-thinning; assisting recovery.



Selective felling; assisted natural recovery.



Dwarf pine growth after storm damage.



Hardwoods recolonising after storm and bark beetle damage.

to differentiate between the two (Appendix 2). However any revision to the scoring protocol would need careful thought because exposed bankside tree roots, underwater roots and overhanging boughs are virtually absent from plantation forest, so there is already a self-limiting factor for plantation forest in the HQA score.

Comparison with other benchmark sites

Adjacent land management and natural disturbances have profound influences on river habitats and their flora and fauna. Our benchmarking surveys have reaffirmed the importance of designated wildlife areas and low intensity farming practices for maintaining and improving the nature conservation interest of riparian woodlands and valley floor meadows as well as the wider catchment landscape^{14,20}. Clear long-term objectives and financial incentives for appropriate land management are essential to achieve ecological goals. Scrub encroachment of species-rich meadows in parts of Slovenia¹⁴, overgrazing and burning of pasture and heath in northern Spain¹⁸ and rapid colonisation of river banks by invasive non-native plant species in southern Portugal¹⁹ are examples where nature conservation interest is being suppressed or lost by inappropriate land management or neglect through land abandonment.

Conversely, proactive management to re-naturalise secondary forest along the Drawa River is a good example where long-term ecological improvements are being planned and implemented²⁰. Re-naturalisation of the spruce plantation in the Tatra National Parks is another example of how careful ecosystem management, including essential non-intervention, can lead to the recovery of ecological and nature conservation interests. The recolonisation of native fir *Picea alba*, larch *Larix decidua* and hardwood species will take a very long time in the High Tatras, assisted by natural disturbances such as avalanches, storms and bark beetle.



Intensively grazed landscape, French Pyrenees.

Vegetation recovery above the tree-line in the High Tatras provides a good contrast with other benchmark study areas where livestock or deer still cause overgrazing - notably goats in the Pyrenees and Picos de Europa, and deer and sheep in parts of the Scottish Highlands. Annex K shows CEN scores we have derived from RHS, other field survey data and photographs for two reaches of a high altitude (reaching 1560m) stream (Le Gave D'Ossau) in the French Pyrenees. Although it was not selected specifically for benchmarking purposes, it was surveyed for developing and testing the CEN standard^{21,22}. Land-use is the key factor affecting the CEN scores, particularly where trees are absent from the banks

and valley floor. Like the Picos de Europa¹⁸, but in contrast to the High Tatras, grazing pressure in this part of the Pyrenees is intense; there are also modifications to the channel to maintain tracks for tourists and farmers, and occasional channel realignment to improve drainage and protect roads. This comparison shows the immense importance of the High Tatra headwaters above the tree-line and (with the exception of inaccessible gorges) the extreme rarity of natural streams in primeval woodland in western Europe.

Aquatic macrophytes

The bryophyte-only MTR taxa list from all our High Tatra sites was very unusual. The only exclusively bryophyte sites in our previous benchmark surveys were one each in the Cévennes, France¹⁶ and the Julian Alps, Slovenia¹⁴ and 10 out of 20 sites in the Picos de Europa¹⁸. Most noteworthy was that no MTR algal taxa were found in any of our High Tatra sites; this affirms very low nutrient status.

The variety and location of bryophytes in several of our sites indicated subtle local differences in environmental conditions. Along some stream margins taxa indicative of acidic conditions, such as notched rustwort *Marsupella emarginata* and yellow fringe-moss *Racomitrium aciculare*, were found growing close to species associated with more base-rich conditions such as Lyon's notchwort *Tritomaria quinqueidentata*, comb-moss *Ctenidium molluscum*, hook-mosses *Palustriella* spp. and sessile grimmia *Schistidium apocarpum*. This variation also occurred in some flushes, indicating complex local geological influences.

Another notable result was the absence of Alpine water-moss *Fontinalis squamosa* and only one recorded location for the usually ubiquitous greater water-moss *Fontinalis antipyretica*. Many bryophytes appeared to be slightly 'deformed' and this may be due to the extremely harsh environment in which they grow; spending many months under winter snow and ice, being subject to intense abrasive scour during snowmelt floods and then baked under the summer sun when the channel partly dries out.

We found several species not recorded during our previous benchmark surveys in mainland Europe^{14,20}. Examples included: Mougeot's Yoke-moss *Amphidium mougeotii*, a species of river gorges that is typical of siliceous rocks with some base influence; western brook-moss *Hygrohypnum eugyrium*, (probably the first record for Slovakia), a species limited in the UK to mountainous areas where rocks are only slightly basic; Zierian hump-moss *Plagiobryum zieri*, a species occurring in the UK only in damp, base-rich areas above 750m; sickle-leaved hook-moss *Sanionia*



Fontinalis antipyretica was found at only one High Tatra site.

(*Drepanocladus uncinata* and *Tritomaria quinquedentata*, both of which are found in flushes, especially calcareous ones; and broad-leaved brook-moss *Hygrohypnum duriusculum*, a rare species in Slovakia³² and very rare in the UK where it is confined to a few mountain streams²⁷.

There were also some floristic similarities between the High Tatra sites and other benchmark surveys¹⁴⁻²⁰. For example, hook-moss *Palustriella* sp. was also common in the Julian Alps of Slovenia, but the geology there is more basic and the moss was either common or dominant. The Julian Alps sites also contained butterbur *Petasites* sp. on the gravel margins¹⁴. Base-rich sites in the Picos de Europa¹⁸ also commonly had hook-mosses *Palustriella* spp. present; however, many of the less ubiquitous bryophyte taxa recorded from the Picos sites differed from those recorded in the High Tatras. In common with high altitude rivers surveyed in the Cévennes area of France¹⁶, featherworts *Plagiochila* spp. were also frequently found along the edges of High Tatra streams.

CONCLUSIONS

We achieved all six of our original objectives and can draw the following conclusions about the High Tatras:

- near-natural streams in most valleys are confined to steep headwater reaches;
- ‘rapid’ stream-flow channels are all very similar, dominated by boulders;
- vegetated mid-channel and side bars occur at a higher frequency than in other similar benchmark sites;
- channel gradient significantly influences stream-flow and habitat character, exemplified by local changes in our study reach on the Biela voda.
- bryophytes exclusively dominate the sparse aquatic macrophyte communities;
- flushes are particularly rich and diverse botanically;
- only dwarf pine, alpine heath and grass above the tree-line and some supra-montane spruce or Swiss pine forest tracts can be considered ‘near-natural’ vegetation - these have not been managed or grazed by livestock for at least 60 years;
- spruce plantation forest in the national parks is very slowly re-naturalising, helped by successional influences such as windstorms, avalanches, bark beetle outbreaks and assisted by careful forest management;



Boulder-dominated streams typify the High Tatras.

- the benthic macroinvertebrate fauna is very limited, probably reflecting the very harsh conditions in these headwaters.

We have reaffirmed the crucial importance of understanding land-use history and explored ways of assessing riparian and catchment land management in relation to habitat quality in river corridors, using the CEN scoring protocol for wider comparison. More work is needed to inter-calibrate ‘departure from natural conditions’ for different bio-geographical regions and in particular the influence of historical plantation forestry, pastoral agriculture and associated successional recovery.

Our RHS and aquatic macrophyte results have added to the STAR⁴ and RHS benchmarking database, further increasing our knowledge about the character and variability of rivers across Europe. We have made recommendations for improving the RHS manual and HQA scoring protocol (Appendix 2) which continue to build on suggestions in previous reports in this series¹⁴⁻²⁰. Together, these should further improve the relevance and quality of RHS in Poland and Slovakia, as well as helping to improve the assessment, management and conservation of rivers across Europe.

We hope that our results will help to promote a European-wide network of expertise that shares data, knowledge and training material. This is particularly relevant in relation to: (i) identifying and protecting near-natural river reaches with ‘high ecological status’ under the Water Framework Directive²⁴; (ii) maintaining the favourable conservation status of rivers designated under the Habitats Directive³⁵.



Mountain ridges, scree, dwarf pine and alpine grassland dominate the landscape above the tree-line.



Vegetated bars occur more frequently than expected.

APPENDIX 1: Notes for the survey sites.

Javorinka . (Tatra 1a - 1d). 6 June 2010.
Four back-to-back surveys (2km).
HQA = 63; 66; 65; 64.
HMS = all 0(1).

A steep, boulder-bed mountain stream in a deep vee valley heavily forested with spruce. Huge boulders in the channel are evidence of regular avalanches and rockfalls. Mid-channel islands are a characteristic feature, particularly in Tatra 1c where partial debris dams have also created naturally impounded habitats, in contrast to the relentless white-water rapids elsewhere.

Extensive flushes occur, particularly in Tatra 1a, whilst a major avalanche track in Tatra 1b has opened up the spruce plantation and is being colonised by hardwood trees and shrubs. Similar re-colonisation has also occurred in storm-damaged parts of the spruce forest in Tatra 1c, which also contains a gorge-like bedrock channel section.

In-channel macrophytes were exclusively bryophytes and these were extremely sparse. Some species growing in the channel also extended up the banks to merge with terrestrial species higher up. The bryophyte assemblage was similar to that found in the other rivers we surveyed (Annex G). The MTR scores of 82, 82, 78 and 79 indicate very low nutrient levels in the water.

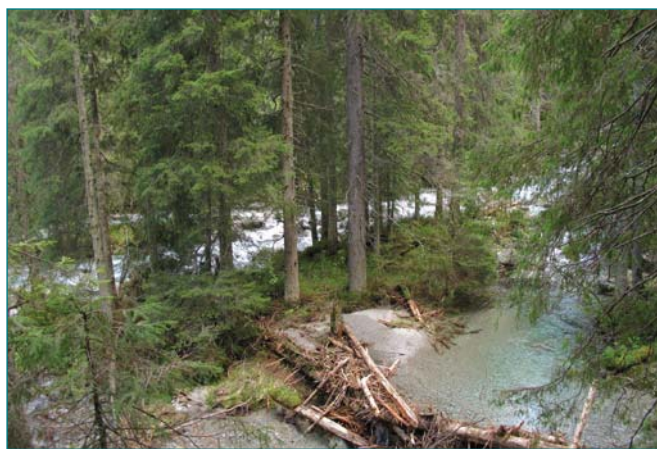


Boulders and whitewater, Tatra 1c.

Biela voda. (Tatra 2a - 2d), 7 June 2010; (Tatra 3a - 3d), 8 June 2010. Eight back-to-back surveys (4km).
HQA = 66; 69; 59; 73; 87; 63; 62; 58.
HMS = 0(1); except 2c (100(2)), 3a (20(2)).

There are three distinct sections, starting with a very steep gradient for the first 1000m. The Litvorový potok (Tatra 2a only) contains a short bedrock gorge section, with boulders and chute flow predominant after the confluence with the Biela voda (Tatra 2b). During this descent, dwarf pine gives way to coniferous plantation with occasional mountain ash. Extensive mature mid-channel islands become a feature in Tatra 2b, with avalanche tracks and huge boulders at the downstream end of this site, where vegetated side bars also appear. The stream gradient becomes less in Tatra 2c, with cobbles replacing boulders as the predominant substratum. Here, the valley floor widens and is terraced.

In the downstream half of Tatra 2d and the upstream half of Tatra 3a there is a 400m length of low gradient (5-10 m/km) river with riffles and point bars. The valley floor is up to 125m wide and the stream splits into two parallel channels with a complex array of natural berms, floodplain terrace, wet and dry sub-channels, backwaters and marshy habitats. Boulders placed along the bank and some fallen tree trunks anchored in place to deflect flow have been used to protect a footpath which follows part of the



Local impoundment caused by a debris dam, Tatra 1c.



A major avalanche has opened up the spruce forest, Tatra 1b.



Mid-channel island, Tatra 1c.



A bedrock chute, Litvorový potok, Tatra 2a.

channel. There is a small gazebo and also a picnic table at a prime photographic location in this reach, reflecting the popularity of this area for hikers.

Downstream from this gentle reach the channel steepens again, with chute flow, broken waves and extensive boulders once again predominant. The forest becomes denser and much more plantation-like, with evidence of old ditches and boundary walls. A recent major avalanche event affecting Tatra 3c must have temporarily blocked the channel and produced a large, boulder-dominated, vegetated side bar immediately downstream.

Mosses and liverworts were more abundant in Tatra 2a-2d than in the Javorinka. Water earwort *Scapania undulata* was relatively common in Tatra 2a and 2b, with encrusting lichen (probably *Verrucaria*) also common in Tatra 2a. The presence of marsh marigold and other plants spreading from the margins reflects abundant shallow flushes in the



Back channel habitat, Tatra 2d.



Mid-channel island, Tatra 2c.

upstream parts, especially in 2a. The high MTR scores (90, 83, 81 and 87 respectively) indicate extremely low nutrient levels.

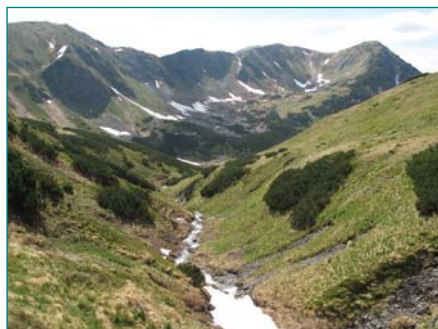
The macrophyte communities in Tatra 3a-3d differed little from other sites we surveyed, with the exception of the gentle section where the channel splits in two. Here, greater water-moss *Fontinalis antipyretica* only occurred in the more sluggish-flowing back channel, growing on tree roots and embedded boulders, with bog-mosses *Sphagnum* sp(p.) common along the swampy margins. Neither were present in the faster-flowing, parallel channel. MTR scores (80-93) were similar to those further upstream (Tatra 2a-2d).



Boulders and white water, Tatra 3a.

Zadná Tichá (Tatra 4a - 4b), 9 June 2010.
Two back-to-back surveys (1km).
HQA = 72; 76. HMS = 0(1); 0(1).
(Tatra 5c - 5a in downstream order), 10 June 2010.
Three consecutive surveys (1.5km).
HQA = 51, 55, 59. HMS = all (0)1.

The Zadná Tichá rises in marshy ground at 1890m altitude and quickly forms a small torrent with a classical step-pool sequence. Snowmelt is a major source of water in late spring, although these upstream reaches will dry out in hot summers. There is a distinct gorge/canyon section (Tatra 5b) with cascades and pools and extensive flushes in places. In Tatra 5a the bedrock channel is steep, with long cascades. At one point the channel course has several right-angled bends, and unusually for a steep bedrock channel, a cobble point bar was present.



Alpine grass/dwarf pine landscape, Tatra 5c.



Waterfall, Tatra 4a.



Storm-damaged spruce trees, Tatra 4b.

Near the source, the catchment vegetation is dominated by alpine grassland (*Nardus stricta*) and dwarf heath. Butterbur is locally common in wet margins. Patchy dwarf pine occurs further down the slopes, becoming more extensive, before re-naturalising spruce plantation appears at about 1500m.

Below the dwarf pine zone (Tatra 4a,b) the stream continues to be very diverse with several waterfalls, numerous pools, luxuriant flushes and regular small landslips that supply boulders and cobbles to the channel. In Tatra 4b the gentler slope produces less diverse habitat generally although there are still excellent flushes. The downstream 100m in Tatra 4b provides graphic illustration of the 2004 storm damage; fallen trees have purposely not been removed, so dozens of spruce trunks still lie in and across the channel. Curiously, dwarf pine/rowan/bilberry is regenerating vigorously on the left bank, but not so well on the right. These face south and are baked in summer.

The three upstream sites (Tatra 5a-c) had MTR scores higher than 90 indicating very low nutrient levels. Marsh forklet-moss *Dichodontium palustre* was found growing only here, extending into the channel from the numerous wet flushes at the margins. Curled hook-moss *Palustriella commutata* (not on either the MTR or JNCC check-list) was common on the edges where the flushes merged into the channel. Species such as the brassica *Arabis soyeri* and marsh marigold were also found along the water's edge.

Stable boulders, a sign of reduced scour, resulted in both Tatra 4a and 4b having a higher number (13) of MTR taxa recorded. Flapworts *Jungermannia* spp. were consistently more common here than elsewhere, as were transparent fork-moss *Dichodontium pellucidum* and claw brook-moss *Hygrohypnum ochraceum*. The MTR scores (91 and 90) indicated very low nutrient levels in the water.



Stepped channel profile and moraine terraces, Tatra 6b.

Tributary of Potok Roztoka (Tatra 6b - 6a in downstream order), 11 June 2010. Two back-to-back surveys (1km). HQA = 51; 55. HMS = 0(1); 0(1). Potok Roztoka (Tatra 6c), 11 June 2010. One 500m survey. HQA = 59; HMS = 0(1).

The main tributary stream flows into a large mountain tarn (Wielki Staw Polski), cutting through glacial moraine and forming a distinct terraced profile. Compared to the Zadná Tichá (Tatra 5a-c) sites, located 1.5-2.0km due west, the channel gradient is relatively gentle and the stream has a stepped profile, but very few pools. Vegetated mid-channel bars and extensive bryophytes indicate relatively stable flow. Dense dwarf pine, dwarf heath, *Nardus stricta* grassland and wet flushes characterise the adjacent vegetation in the alpine landscape.

The Potok Roztoka flows out of the very deep (79m) mountain tarn, Wielki Staw Polski and within Tatra 6c it cascades down Siklawka, a 70m high waterfall. The steep terrain and dense dwarf pine made surveying difficult, so 50m spot-check locations had to be estimated by imaginative use of the range-finder and GPS. Not surprisingly, the channel is dominated by chute flow, bedrock and boulders. A major avalanche track was a feature at the downstream end. Scree, dwarf pine and bilberry dominate the landscape.

All three sites had MTR scores higher than 90. Compressed flapwort *Nardia compressa* was more common here than elsewhere, especially in Tatra 6a and 6b. Earwort *Scapania* spp. and notched rustwort *Marsipella emarginata* were more common here than in others sites we surveyed. Both occurred primarily on bedrock in both moderate current



Siklawka, the tallest waterfall/cascade in Poland, Tatra 6c.

and in torrent flows upstream from the waterfall. Pasque flower *Pulsatilla scherfelii* was abundant in cracks in rocks above water level and on the banks. Bryophyte cover was consistently greater in Tatra 6b than in any other rivers we surveyed, presumably due to a combination of the gentle gradient and the extensive blanket bog and flushes that would maintain flow even in the driest summer conditions.

APPENDIX 2: Recommendations for improving the RHS manual.

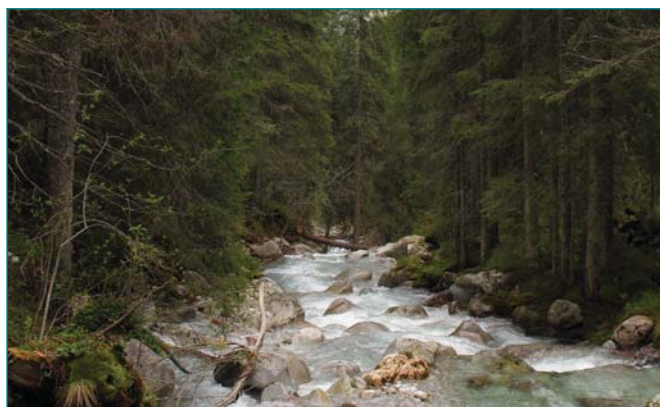
These recommendations and observations, listed in alphabetical order, are in addition to those in previous benchmark reports¹⁴⁻²⁰.

Avalanche tracks: *it is recommended* that these are recorded as a special feature in section M on the RHS form, as well as 'scree' land-use in Section H. This is because they provide morphological evidence of natural instability. In the spruce plantation forests of the High Tatras they represent important sources of natural regeneration because they are colonised by native species such as bilberry, broadleaf shrubs and, at higher altitudes, dwarf pine. Indicating whether the tracks are predominantly vegetated or unvegetated is also recommended.



Avalanche track colonised by dwarf pine.

Bankside trees: *it is recommended* that for deep vee valleys with little or no obvious break in slope the first line of trees growing at trash-line level defines the 'riparian zone' (equivalent to 'banktop') boundary. This will also determine whether native or plantation trees are included in the banktop land-use.



Plantation forest trees growing at the equivalent of banktop level.

CEN standard and HQA: *it is recommended* that when interpreting survey results for a river reach the CEN standard score (See Annex J) is used in conjunction with HQA. This will help to confirm the nature of the riparian trees and adjacent land-use because the CEN attributes use departure from naturalness as a criterion, whereas HQA has limited scope in this respect.

Chaotic flow: where two or three flow types are almost equally co-dominant, surveyors should avoid using 'chaotic flow' for spot-checks (Section E), but select the fastest flow-type. In torrents virtually every spot-check could be

recorded as chaotic flow but this 'catch-all' category does not provide useful information. Site photographs will reveal the overall 'chaotic flow' of torrents to support the sweep-up summary of flow-types recorded in Section K of the RHS form.



Chaotic flow is a feature of boulder-bed torrents.

Discrete deposits (qualifying criterion): the current guidance rule for minimum size ($> 5\text{m}^2$) is not appropriate for discrete deposits in small streams. *It is recommended* that, provided the morphological criteria for discrete deposit are met, a scaled 'rule of thumb' guidance for minimum size is developed and tested. For example, using 0.5m^2 per 1m stream width would mean a minimum size of 1.5m^2 in a 3m wide stream, whilst 5m^2 would be the minimum qualifying area for a 10m wide stream.



Discrete deposit in a small stream.



A vegetated discrete deposit.

Discrete deposits (vegetated): discrete deposits are usually predominantly one particle size (e.g. sand or gravel). However, pebble or cobble discrete deposits in steeper streams often have gravel and sand infill. These deposits are usually un-vegetated, but when colonised by plants they can look like a smaller version of a vegetated side bar. Therefore, *it is recommended* that vegetated discrete deposits (i.e. > 50% vegetated area) are distinguished by putting a circle round the 'tick' made in the appropriate box, or by creating a **separate vegetated discrete deposit** category in Section K of the RHS form.

Dwarf pine: *it is recommended* that dwarf pine should be recorded as 'scrub' in section H of the form because that is the land-use category it most closely resembles. However, because dwarf pine can also represent a specific biogeographic zone, it should be distinguished by putting a circle round the 'SH' code and noting that this annotation specifically represents dwarf pine.

GPS readings: *we reaffirm previous recommendations* that field-based GPS readings should be calibrated and cross-checked with map-based ones because of errors when satellite coverage is poor, particularly in heavily-wooded valleys.

Re-naturalising coniferous plantation: *it is recommended* that re-naturalising plantation forest should be recorded as coniferous plantation (CP) land-use in Section H, but that the suggested criteria for structure and species composition in Table 6 are noted and used to determine the HQA scoring.



Re-naturalising plantation forest. See Table 6.

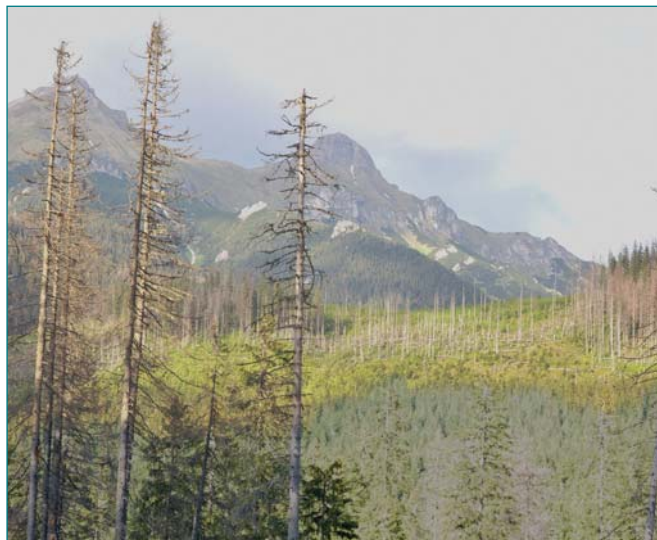
Snow-melt: *it is recommended* that snowmelt should be recorded as a 'factor affecting conditions' in Section A if it is causing elevated water levels.



Snow-melt will increase water levels downstream.

Spot-checks and waterfalls: *it is recommended* that a spot-check is included on cascades and waterfalls more than 50m high. Locating the spot-check will be difficult (see page 24), but innovative use of a range-finder and GPS can provide a practical means for doing this. **NB: on no account should health and safety considerations be compromised in doing RHS where high waterfalls are concerned.**

Storm damage: *it is recommended* that significant areas of storm-damaged trees (particularly those areas of wind-thrown trees left unmanaged) are noted as part of 'overall characteristics' (Section P). This will help to provide context to the site description and interpretation of land-use influence on the river channel. Significant areas of trees damaged by bark beetle should also be noted.



Storm-damaged spruce forest is a feature of the High Tatras.

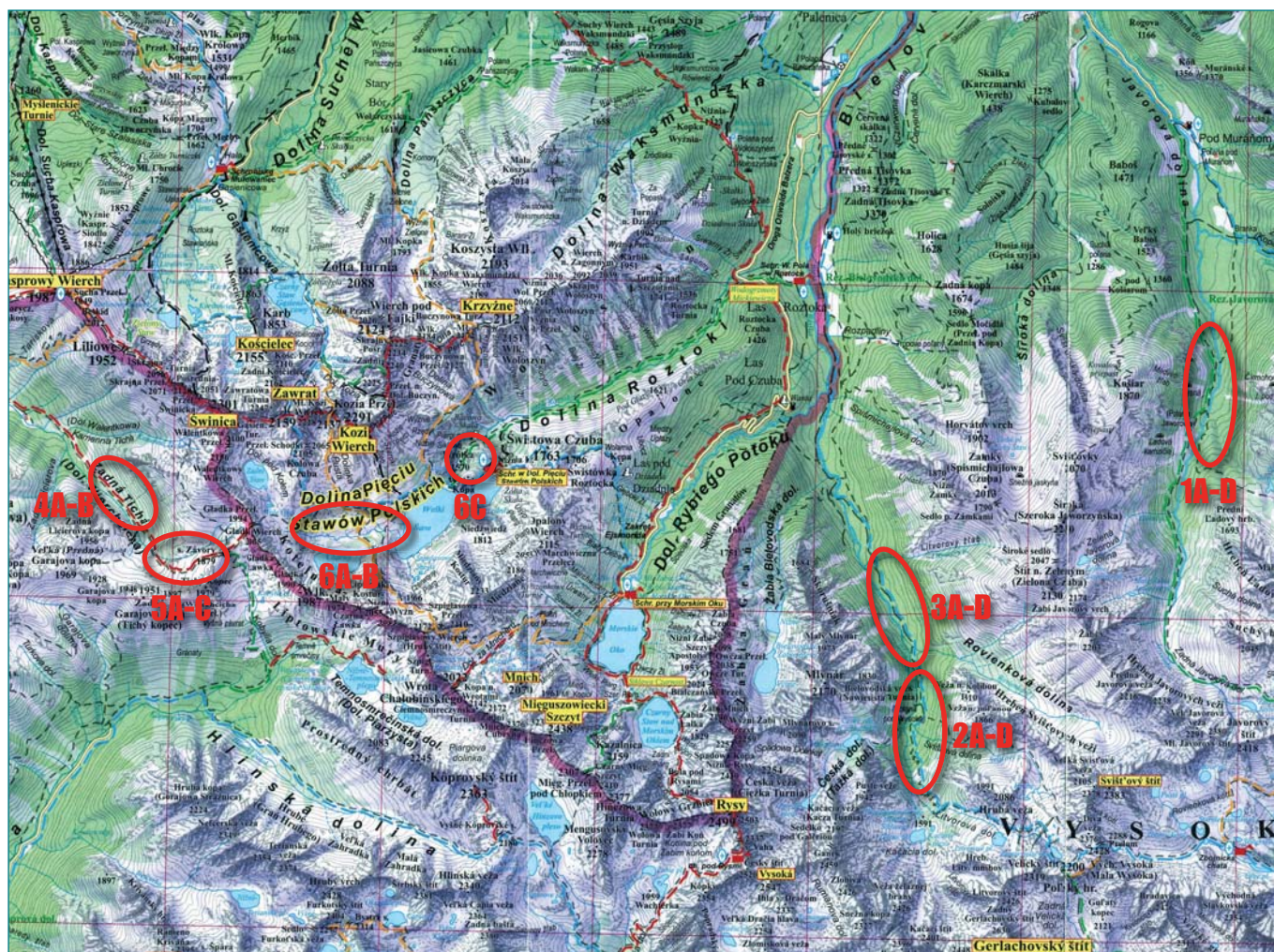
Tree-line: *it is recommended* that if it is known that all or part of a site is above the natural climatic tree-line it should be noted as part of 'overall characteristics' in section P.

Valley shape: valley shape is determined by the near-horizon view, as observed from the channel. This is because the information is used, together with the presence or absence of a flat valley bottom and the type of bank material, to assess constraints to lateral channel movement. In the High Tatras, deep vee was the predominant near-horizon profile, but usually within an overall 'U' shaped glaciated valley. In such cases, *it is recommended* that this combination is noted in Section B (predominant valley form).



Dense dwarf pine marks the natural tree-line in the High Tatras.

ANNEX A: Location of survey sites.



ANNEX B: Main characteristics of the survey sites.

Sites shown in downstream sequence. Superscripts refer to site number.

River name and site number	Javorinka 1a - 1d	Biela voda 2a - 2d	Biela voda 3a - 3d	Zadná Tichá 5c, 5b, 5a	Zadná Tichá 4a, 4b	Potok Roztoka 6b, 6a, 6c
Predominant valley form (within glacial valley)	Deep vee	Deep vee	Deep vee	Deep vee	Deep vee	Shallow vee ^{b,a} Deep vee ^c
Predominant catchment geology	Granitoids, some limestone	Granitoids	Granitoids	Granitoids	Granitoids	Granitoids
Height of source (m)	2010	2013	2013	1890	1890	1870
Valley relief (m)	600	700	850	250	700	300
Distance from source (km)	3.5 ^a 4.0 ^b 4.5 ^c 5.0 ^d	1.85 ^a 2.35 ^b 2.85 ^c 3.35 ^d	3.85 ^a 4.35 ^b 4.85 ^c 5.35 ^d	0.5 ^c 1.0 ^b 1.5 ^a	2.45 ^a 2.95 ^b	0.65 ^b 1.15 ^a 2.55 ^c
Altitude (m)	1310 ^a 1255 ^b 1215 ^c 1185 ^d	1500 ^a 1360 ^b 1308 ^c 1299 ^d	1293 ^a 1245 ^b 1215 ^c 1195 ^d	1820 ^c 1700 ^b 1570 ^a	1460 ^a 1395 ^b	1720 ^b 1690 ^a 1580 ^c
Channel slope (m/km)	110 ^a 90 ^b 80 ^c 70 ^d	380 ^a 180 ^b 34 ^c 12 ^d	30 ^a 100 ^b 50 ^c 40 ^d	200 ^c 260 ^b 170 ^a	190 ^a 80 ^b	80 ^b 90 ^a 280 ^c
Trashline/ bankfull width (m)	12.0 ^a 15.0 ^b 13.0 ^c 15.0 ^d	5.0 ^a 12.0 ^b 11.0 ^c 12.0 ^d	5.0 ^a 13.0 ^b 20.0 ^c 14.0 ^d	2.5 ^c 4.5 ^b 6.5 ^a	4.5 ^a 7.0 ^b	7.0 ^b 8.0 ^a 19.0 ^c
Predominant flow-types [†]	Chute-broken wave ^{a,d}	Chute ^a Broken wave-chute ^b Broken wave ^c Broken-unbroken wave ^d	Unbroken wave-chute ^a Chute-broken wave ^{b,d} Broken wave-chute ^c	Chute ^{c-a}	Chute-broken wave ^c Broken wave ^b	Chute-unbroken wave ^c Chute-freefall- broken wave ^c
Predominant channel substrata [†]	Boulder ^{b,c} Boulder-cobble ^d	Boulder ^c Boulder-cobble ^b Cobble ^{c,d}	Pebble-boulder ^a Boulder ^{b,c} Cobble-boulder ^d	Bedrock-boulder-cobble ^c Boulder-cobble-pebble ^b Bedrock-cobble ^a	Boulder-cobble ^c Cobble-boulder ^b	Cobble ^b Cobble-boulder ^a Bedrock-boulder ^c
HQA	63 ^a 66 ^b 65 ^c 64 ^d	66 ^a 69 ^b 59 ^c 73 ^d	87 ^a 63 ^b 62 ^c 58 ^d	68 ^c 60 ^b 53 ^a	72 ^a 76 ^b	51 ^b 55 ^a 59 ^c
HMS (and class)	0(1) ^{a-d}	0(1) ^{a,b,d} 100(2) ^c	20(2) ^a 0(1) ^{b,d}	0(1) ^{c-a}	0(1) ^{a,b}	0(1) ^{c-a}
MTR	82 ^a 78 ^b 79 ^d	90 ^a 83 ^b 81 ^c 87 ^d	80 ^a 93 ^b 90 ^c 88 ^d	93 ^c 92 ^b 93 ^a	91 ^a 90 ^b	93 ^{b,a} 94 ^c
MIR	84 ^a 81 ^b 78 ^c 80 ^d	88 ^a 83 ^b 82 ^c 87 ^d	79 ^a 89 ^b 86 ^{c,d}	91 ^c 90 ^b 91 ^a	89 ^a 87 ^b	92 ^b 93 ^a 93 ^c

[†] recorded at 3 or more spot-checks.

ANNEX C: HQA sub-scores and total scores. Sites shown in downstream sequence.

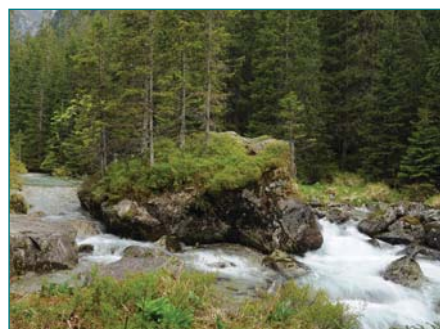
River	Javorinka				Biela voda								Zadná Tichá					Potok Roztoka		
Site number	1a	1b	1c	1d	2a	2b	2c	2d	3a	3b	3c	3d	5c	5b	5a	4a	4b	6b	6a	6c
Flow-types	10	11	11	10	8	10	8	9	10	10	9	9	10	9	10	11	9	10	11	9
Channel substrata	9	10	7	9	7	9	7	7	9	8	7	10	9	10	10	9	8	5	8	7
Channel features	11	10	9	8	10	11	8	9	14	10	9	9	9	10	12	8	11	6	7	9
Bank features	0	2	2	2	1	2	3	10	8	2	6	3	1	2	4	2	3	3	2	1
Bank vegetation structure	11	10	12	10	6	9	12	12	12	11	11	11	2	6	6	8	8	4	7	8
In-stream vegetation	2	2	2	1	2	2	2	1	1	2	1	1	2	2	2	2	2	2	2	2
Land-use [‡]	3	5	6	6	14	5	6	5	6	4	3	2	14	14	14	9	9	14	14	14
Trees and associated features	10	10	10	14	10	14	10	10	10	10	10	9	1	1	4	14	16	0	0	1
Special features [‡]	7	6	6	4	8	7	3	10	17	6	5	4	5	6	6	9	11	7	4	8
Total HQA Score	63	66	65	64	66	69	59	73	87	63	62	58	53	60	68	72	76	51	55	59

‡ assumptions made about near-natural land-use and special features (see Table 6).

ANNEX D: HMS and habitat modification class. Sites shown in downstream sequence.

River	Javorinka				Biela voda								Zadná Tichá					Potok Roztoka		
Site number	1a	1b	1c	1d	2a	2b	2c	2d	3a	3b	3c	3d	5c	5b	5a	4a	4b	6b	6a	6c
HMS score	0	0	0	0	0	0	100	0	20	0	0	0	0	0	0	0	0	0	0	0
Habitat modification class	1	1	1	1	1	1	2	1	2	1	1	1	1	1	1	1	1	1	1	1

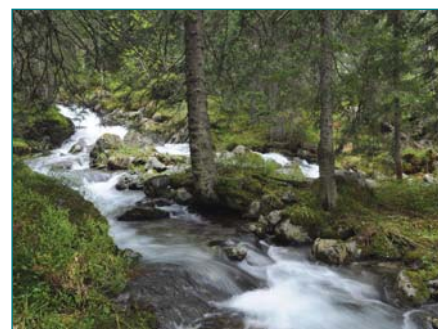
Vegetated boulder/bedrock.



Natural berm/terrace.



Mature island.



All these features were all more common in the High Tatras than in similar benchmark sites surveyed elsewhere.

ANNEX E: Selected features in the High Tatras and other benchmark sites. Percentage occurrence in 'rapid' and 'rapid-moderate' stream-flow character above and below 600m altitude. Bold numbers indicate notable differences within stream-flow type.

Stream-flow type	Rapid		Rapid	Rapid-moderate		Rapid-moderate
Altitude	Sites > 600m		Sites <600m	Sites > 600m		Sites <600m
Location	High Tatras	Other	All	High Tatras	Other	All
Waterfalls	50	33	28	0	40	16
Exposed bedrock	69	67	89	0	72	77
Exposed boulders	100	100	100	100	92	97
Vegetated boulder/bedrock	75	•	•	75	•	•
Unvegetated mid-channel bars	94	50	22	75	60	49
Vegetated mid-channel bars	75	33	28	100	52	27
Mature islands	75	50	22	75	20	30
Unvegetated side bars	69	83	56	50	88	84
Vegetated side bars	82	33	11	75	32	26
Unvegetated point bars	6	0	11	50	20	31
Vegetated point bars	6	0	6	25	4	10
Natural berm/terrace	6	•	•	100	•	•
Riffles	0	0	0	50	44	46
Pools	94	83	61	75	76	71
Number of sites	16	5	18	4	25	90

• Insufficient data

Annex F: MTR survey results.

STR = Species Trophic Rank; SCV = Species Cover Value (scale 1-9); CVS – Cover Value Scores (STR x SCV). *TAT3Ai in main channel, TAT3Aii in back channel.

Site Names	STR	TAT1A	TAT1B	TAT1B	TAT1D	TAT2A	TAT2B	TAT2C	TAT2D	*TAT3Ai	*TAT3Aii	TAT3B	TAT3C	TAT3D	TAT4A	TAT4B	TAT5A	TAT5B	TAT5C	TAT6A	TAT6B	TAT6C	TAT7												
	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS	SCV	CVS													
<i>Chiloscyphus polyanthos</i>	8	0	0	0	0	0	1	8	1	8	0	0	1	8	1	8	1	8	1	8	0	0	1	8											
<i>Jungmannia</i> sp.(.)	8	0	0	0	0	1	8	2	16	1	8	1	8	1	8	2	16	2	16	0	0	1	8	1	8	0									
<i>Marsipella emarginata</i>	10	0	0	0	0	0	0	0	0	0	0	0	0	0	1	10	0	2	20	1	10	2	20	6	60	0									
<i>Nardia compressa</i>	10	1	10	0	0	0	0	0	0	0	0	0	0	0	1	10	0	0	0	0	1	10	1	10	0	0									
<i>Pellia endiviifolia</i>	6	1	6	0	1	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									
<i>Pellia epiphylla</i>	7	0	0	0	0	0	0	0	0	0	0	0	1	7	1	7	1	7	1	7	0	0	0	0	0	0									
<i>Scapania undulata</i> agg.	9	1	9	2	18	1	9	6	54	4	36	3	27	1	9	3	27	4	36	1	9	2	18	3	27	4	36	6	54	7	63	6	54	1	9
<i>Blindia acuta</i>	10	1	10	1	10	0	1	10	1	10	1	10	2	20	1	10	1	10	2	20	1	10	3	30	2	20	1	10	0	0	0	0	0	0	
<i>Brachythecium plumosum</i>	10	1	10	1	10	1	10	1	10	1	10	1	10	1	10	2	20	3	30	3	30	0	1	10	1	10	1	10	1	10	1	10	1	10	
<i>Brachythecium rivulare</i>	8	1	8	1	8	0	0	1	8	1	8	1	8	0	1	8	0	1	8	1	8	0	1	8	1	8	1	8	3	24	0	0	0	0	
<i>Bryum pseudotriquetrum</i>	9	1	9	2	18	2	18	1	9	2	18	1	9	1	9	2	18	2	18	2	18	1	9	1	9	1	9	1	9	0	0	0	0	0	0
<i>Dichodontium pellucidum</i>	9	1	9	2	18	1	9	1	9	0	0	1	9	1	9	1	9	1	9	1	9	2	18	0	1	9	0	1	9	0	2	18	0	0	0
<i>Dichodontium palustris</i>	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<i>Fontinalis antipyretica</i>	5	0	0	0	0	0	0	1	5	0	0	6	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<i>Hygroamblystegium tenax</i>	5	1	5	2	10	2	10	0	1	5	1	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	10	0	0	0	0	
<i>Hygrohypnum ochraceum</i>	9	1	9	2	18	2	18	1	9	0	0	0	0	0	1	9	3	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<i>Philonotis fontana</i>	9	0	0	0	0	0	0	0	0	0	0	0	1	9	0	0	1	9	0	0	1	9	1	9	1	9	1	9	0	0	0	0	0	0	
<i>Polytrichum commune</i>	10	0	0	0	0	0	0	0	0	1	10	2	20	0	0	1	10	0	0	0	0	1	10	0	1	10	0	1	10	0	0	0	0	0	
<i>Platyhypnidium riparioides</i>	5	1	5	1	5	1	5	0	1	5	2	10	1	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	20	0	0	0	0	
<i>Racomitrium aciculare</i>	10	0	0	0	0	1	10	1	10	1	10	1	10	0	1	10	1	10	1	10	0	1	10	1	10	0	1	10	0	0	0	0	0	0	
<i>Sphagnum</i> sp.(.)	10	0	0	0	0	0	0	0	0	0	3	30	0	0	0	0	1	10	0	1	10	2	20	0	0	0	0	0	0	0	0	0	0	0	
SCV AND CVS TOTALS	11	90	14	115	13	102	9	71	12	108	20	158	11	100	8	71	11	97	18	163	23	207	21	195	15	138	19	176	21	196	19	178	14	99	
MTR SCORES		82	82	78	79	89	83	81	87	90	79	91	89	88	91	90	93	92	93	93	93	94	71												
MIR SCORES		82	82	79	79	90	83	81	87	91	80	93	90	88	91	90	93	92	93	93	94	71													

ANNEX G: JNCC macrophyte survey results.

Figures (scale 1-3) are relative, and absolute, estimates of cover within the river channel (first two figures) and the second two figures are estimates of cover for the margins (if only two figures, these are for margins).

JNCC Taxa	TAT1A	TAT1B	TAT1C	TAT1D	TAT2A	TAT2B	TAT2C	TAT2D	TAT3A	TAT3B	TAT3C	TAT3D	TAT4A	TAT4B	TAT5A	TAT5B	TAT5C	TAT6A	TAT6B	TAT6C
Filamentous algae													1100	1100				1100	1100	
Encrusting lichen									1111	1111	1111	1111	1111	1111				11	11	11
Foliose lichen	11	11	11	11	3322	2211	1111	1111												
Chiloscyphus polyanthos						1111	1111	11	1111		1111	1111	1111							
Conocephalum conicum	11	11	11									11								
Jungemannaia sp(p.)	1111				1121	2121	2121	11	2121	1111	1121	1121	2121	2121	1122	2222	1111	1111	1111	1111
Marchantia polymorpha																				
Marsipella emarginata													1111		2222	2222	1111	1121	1122	3333
Nardia compressa													1111					1111	1111	
Pellia endivifolia	11	11	11	11																
Pellia epiphylla					1111	1121	1111	11		1111	1111	1111	1111	1111	1111	1111	1111			
Scapania undulata agg.	3121	3121	3121	2111	3333	3333	3222	3121	3221	3232	3121	3221	3232	3232	3232	3232	3232	3333	3333	2222
Blindia acuta	3111	2111	1100	1100	1111	2222	2222	1111		1100	1100	1100	2121	1111	2222	1111	3232	2222	2222	1111
Brachythecium plumosum	2121	1121	2121	2121	1122	2222	1111	2121	1121	2132	3121	3232	3232	2132	2222	2121	1111		1111	1111
Brachythecium rivulare	2221	1121	2121	11		1111	1111	1111	1111	1121	1111	11	2121	1111	1111	1111	1111		1111	1111
Bryum pseudotriquetrum	2121	2131	2131	2121	2222	2222	2232	1121	1121	1121	2132	2132	1121	1111	1122	1111	1111	1111	1111	1111
Cindricus fontinaloides					1111	1111	1111	11	11	1111	1111									
Cratoneuron filicinum	3132	3131	2131	2121																
Dichodontium pellucidum	2132	3131	2131	2121	1111	1111	1121	1111	1111	1121	1121	1111	2132	2121	1111	1111	2121	1111	1111	1111
Dichodontium palustris													1111		1111	1111	1111			
Fontinalis antipyretica							1111		3211											
Hygroamblystegium tenax	3132	2131	2131	3131																
Hygrohypnum ochraceum	2111	3121	3121	2121	1111	1111	1111	2111	2111	1111	1100	1111	1111	3221						
Hygrohypnum luridum	1111	1111		1111			1100		1100		1100		1100	1111		1111	1111	1111	11	
Lepidodictyum riparium								11												
Philonotis fontana										1111	1111	1111			1111	1111	2222	1111	2222	1111
Playhyphnum riparioides	2111	2111	2111	2111		1111	2121	1111	1111											
Polytrichum commune	11	11	11		11	11	11		1121	11	11	11	1111	1111	1111	1111		1111	1111	1111
Racomitrium aciculare	11	2111	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111	1121	1111	2121	2111	1111			
Schistidium rivulare	2121	3121	2121	2111	1111	1111	1111	2121	1111	1111	1121	3232	1121	1111	1121	1122	1111			
Sphagnum sp(p.)			11	11	11	1111	1111	1121	1133	11		11	1111	1111	1111	1122	1111	2222	2233	1111
other ferns	11	11	11	11	11	11	11	11	11	11	11	11	11	11						
Caltha palustris	11	11	11	11	1133	1122	21	1132	2121	11	11	11	1111	1111	1121	1121	1121	1122	1122	11
other dicotyledons	21	31	31	21	1122	1122	1122	1132	2133	11	21	11	1121	1121	1122	1132	1132	2133	1133	1111
Salix sp(p.)									11	11	11	11	11	11						
conifers	21	21	221	21	11	11		11	11	11	11	11	11	11	11	11	11	1111	1111	11
other trees and shrubs	11	11	11	11	22	22	22	21	21	11	21	11	1121	1121	1111	1111	21	11	11	11
Molinia caerulea									1122				21					22	1122	
Nardus stricta																		22	1122	
other monocotyledons	11				22	11	22	32	2133	21	21	21	1121	1111	1121	1121	1121	1122	1122	11

ANNEX H: Water chemistry.

Water samples were collected in full, sealed containers for laboratory analysis, undertaken at 16-18°C within 20 days using calibrated conductivity and pH meters. Duplicate semi-quantitative titration undertaken for calcium, chloride and carbonate hardness (total carbonate hardness of Ca and Mg). Chloride and nitrate not detected.

River and site number	pH	Conductivity (µS/cm)	Calcium (mg/l)	Total hardness (Ca and Mg as carbonate)
Javorinka (1a)	6-6.5	27	Trace	Not detectable
Biela voda (2a)	6-6.5	20	Trace	Not detectable
Biela voda (3c)	6-6.5	20	Not detectable	Trace
Zadná Tichá (5c)	6.5-7.0	12	Not detectable	Not detectable
Zadná Tichá (4a)	6.5-7.0	28	Not detectable	Not detectable
Potok Roztoka (6b)	6.5-7.0	12	Not detectable	Not detectable

ANNEX J: CEN scoring attributes.

1. Channel geometry

1a: Planform (reach-based change in sinuosity)

1b: Channel section (changes to long-section and cross-section)

2. Substrata

2a: Extent of artificial material (e.g. concrete, rubble, gabion baskets)

2b: 'Natural' substrate mix or character altered

3a! Aquatic vegetation management

3b! Extent of woody debris if expected

4! Erosion/deposition character

Presence of in-channel features such as gravel bars, etc.

5. Flow

5a! Impacts of artificial in-channel structures within the reach

5b: Effects of catchment-wide modifications to natural flow character (upstream of the reach evaluated) (e.g. by hydropower dams, abstractions, etc.)

5c: Effects of daily flow alteration (e.g. hydro-peaking)

6! Longitudinal continuity as affected by artificial structures - Reach-based and local impacts of sluices and weirs on ability of biota (e.g. migratory fish) to travel through reach, and sediment to be transported naturally.

7. Bank structure and modifications - Extent of reach affected by artificial bank material (% of bank length)

8. Vegetation type/structure on banks and adjacent land - Land cover in riparian zone (% of bank length)

9. Adjacent land-use and associated features - Land cover beyond the riparian zone

10. Channel-floodplain interactions

10a. Degree of lateral connectivity of river and floodplain (Extent of floodplain not allowed to flood regularly due to engineering - based on hydromorphological surveys)

10b. Degree of lateral movement of river channel (Capacity of river to migrate naturally within its floodplain)

!These attributes can only be assessed qualitatively.

ANNEX K: CEN results. Scores for sites and reaches surveyed in the High Tatras and the Brousett (French Pyrenees).
CEN scores: ● 1*; ● 1; ● 2; ● 3; ● 5; ● 1 = attributes assessed qualitatively only; ● overall reach assessments

CEN attribute codes	Javorinka				Biela Voda										Zadná Tichá					Potok Roztoka			Brousett				
	1A	1B	1C	1D	1	2A	2B	2C	2D	3A	3B	3C	3D	2&3	2&3+	5A	5B	5C	4A	4B	4&5	6A	6B	6C	6	B1	B2
1a															2											1	3
1b															2											1	3
2a															1												1
2bl															1												1
3al																											
3bl														1	3						1					1	5
4l														3	3											1	1
5al																										1	1
5b																											
5c																											
6l																											
7															3											1	3
8	5	5	5	5	5	1	5	5	3	3	5	5	5	5	5				3	3	1					5	5
9	5	5	5	5	5	1	5	5	5	5	5	5	5	5	5				5	5	3					5	5
10a															1											1	1
10b															3											1	3

ANNEX I: Benthic macroinvertebrates. Percentage taxon composition and associated indices from two survey streams. Nearest RHS sites shown in brackets.

Macroinvertebrate taxa	Score	Biela voda (Tatra 2d)	Biela voda (Tatra 3a)	Tributary (Tatra 6b)	Potok Roztoka Tributary (Tatra 6b)	Upstream Siklawa (Tatra 6c)	Downstream Siklawa (Tatra 6c)
Oligochaeta	2	37.5%	66.5%	7.0%	36.5%	14.2%	24.1%
Erpobdellidae	-	-	-	-	-	0.6%	-
EPHEMEROPTERA							
Baetidae	6	1.1%	0.4%	-	-	2.2%	0.4%
Heptageniidae/Rhithrogena	8	0.7%	0.5%	-	-	-	-
PLECOPTERA							
Perlodidae	7	-	-	-	0.4%	-	2.1%
Taeniopterygidae	9	0.6%	-	-	-	-	-
Nemouridae	6	0.4%	-	1.4%	0.6%	-	-
Capniidae	8	-	-	10.1%	9.4%	-	2.3%
Leuctridae	7	-	-	10.7%	-	0.6%	2.7%
TRICHOPTERA							
Rhyacophilidae	7	0.3%	-	-	-	0.6%	2.7%
Philopotamidae	8	-	-	-	0.8%	-	-
Limnephilidae	7	0.3%	1.0%	-	-	14.6%	-
Polycentropodidae	6	-	-	-	-	-	0.6%
Goeridae	9	-	-	-	-	2.5%	-
DIPTERA							
Limoniidae	6	3.4%	-	-	5.2%	5.7%	9.6%
Psychodidae	1	3.4%	-	-	-	1.6%	-
Blephariceridae	10	1.9%	-	-	-	-	-
Chironomidae	3	34.5%	27.4%	57.7%	47.0%	42.1%	46.5%
Simuliidae	6	16.0%	4.3%	13.0%	-	13.0%	11.5%
COLEOPTERA							
Elmidae	7	-	-	-	-	2.2%	-
Number of specimens		733	829	355	479	316	523
Number of families		12	6	6	7	12	10
BMWP (PL) index		71	32	32	40	64	58
Value of biodiversity index		4.2	2.06	2.35	2.61	4.8	3.68
% Ephemeroptera, Plecoptera, Trichoptera (EPT)		4	1.9	22.2	11.2	20.5	10.8
Average Score Per Taxon (ASPT)		5.92	5.33	5.33	5.71	5.33	5.8

ANNEX L: Ad hoc wildlife observations.

	Javorinka	Biela voda	Zadná Tichá	Potok Roztoka	Košcieliski potok
Insects					
Camberwell beauty <i>Nymphalis antiopa</i>	•	•			•
Large wall brown <i>Lasiommata maera</i>			•		
Map butterfly <i>Araschnia levana</i>					•
Birds					
Dipper <i>Cinclus cinclus</i>	•	•	•		
Grey wagtail <i>Motacilla cinerea</i>	•	•	•	•	•
Nutcracker <i>Nucifraga caryocatactes</i>	•	•		•	
Mammals					
Brown bear <i>Ursus arctos</i>	•	•	•		
Chamois <i>Rupicapra rupicapra tatrica</i>			•	•	
Marmot <i>Marmota marmota latirostris</i>			•	•	
Red deer <i>Cervus elaphus</i>			•		



Camberwell beauty *Nymphalis antiopa*.

WEB SITES

Google Earth: <http://earth.google.com/index.html>

RHS: www.rhs@environment-agency.gov.uk

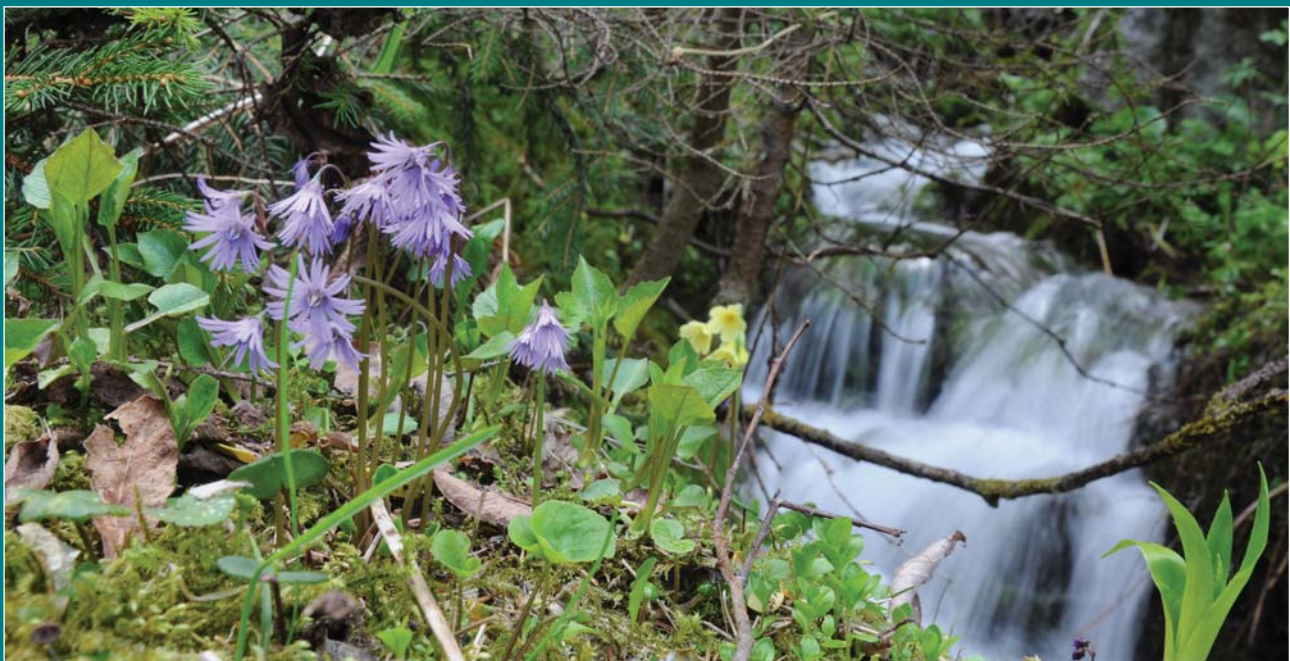
STAR: www.eu-star.at

WISE: <http://www.eea.europa.eu/themes/water>

GLOSSARY OF ACRONYMS

ASPT	Average Score Per Taxon
BMWP(PL)	Biological Monitoring Working Party score (Polish version)
CEH	Centre for Ecology and Hydrology
CEN	Committee for Standardisation
CORINE	Co-ORDination of INformation on the Environment
GPS	Global Positioning System
HMC	Habitat Modification Class

HMS	Habitat Modification Score
HQA	Habitat Quality Assessment
JNCC	Joint Nature Conservation Committee
MIR	Makrofitowy Indeks Rzeczy (Macrophyte Index for Rivers)
MTR	Mean Trophic Rank
NERC	Natural Environment Research Council
PCA	Principal Components Analysis
RHS	River Habitat Survey
SAC	Special Area of Conservation
STR	Species Trophic Rank
STAR	STAndardisation of River Classifications
Tatra 1a etc	RHS site code used in the High Tatra Mountains
UNESCO	United Nations Education, Scientific and Cultural Organization
WFD	Water Framework Directive
WISE	Water Information System in Europe



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