Fact sheet: Small, single- and multi-thread, mid altitude rivers

General description

Valley- and planform	Valleys are U-shaped, partly confining the river planform which is mostly sinuous and partly straight or meandering. Due to the small river size, confinement and/or cohesive river banks, channels are usually single-thread.
Hydrology	Naturally, cross-sections are wide and shallow, and the floodplain is inundated several times a year. Most rivers are permanent and the discharge regime is flushy with pronounced high flow events, especially in boreal and continental rivers with snowmelt floods.
Morphology	Alluvial rivers with typical alternating bars, riffle-pool sequences, and irregular banks partly shaped by tree roots. Although dominated by gravel, bed material of varying size in the sand to cobble range may be present, as well as organic substrates like leaves and large amounts of wood which locally form wood jams that might span the entire channel. Sediments are usually well sorted to reflect the diverse flow pattern and bed morphology.
Chemistry	Depending on the geology pH can vary from 6.5 to 8.5. A distinction can be made between siliceous and calcareous rivers, with neutral to weak alkaline pH-values in calcareous rivers (e.g. flysch region) and siliceous rivers being vulnerable to acidification, especially under spruce forest (e.g. boreal rivers).
Riparian zone	The usually narrow floodplain is dominated by deciduous trees, mainly alder and in addition spruce in boreal rivers, which more or less fully shade the river bed.

Photo: Small, single-thread, mid altitude rivers with bed material of varying size and geology: Siliceous rivers dominated by gravel (Central Europe, upper left, photo A. Lorenz) and cobble to boulder (boreal river, upper right), and a calcareous cobble-bed river in a continental region (flysch region, bottom, photo K. Brabec).

Pressures

Major pressures

The small single-thread rivers in lower-mountain areas are affected by multiple-pressures, most of which fall in three categories: First, point sources (e.g. organic pollution) are still the main pressure in some regions (e.g. Eastern Europe). Water quality has substantially improved in other regions (e.g. Central Europe) but recent studies indicate that even moderate water pollution might still affect biota, especially sensitive macroinvertebrate species. Second, diffuse source pollution including nutrients and fine sediment input. Third hydromorphological alterations, especially missing riparian vegetation, bank fixation, narrowing / entrenchment, and straightening, as well as migration barriers and associated upstream impoundments. Moreover, the remaining riparian vegetation and in-channel large wood are often removed during maintenance.

Furthermore, small, single-thread, mid altitude rivers in some regions are affected by very specific pressures. For example, many boreal rivers in Finland and Sweden are still running through forested areas (i.e. catchment-scale land use pressure is much lower compared to e.g. more densely populated mountain regions in Central Europe) but most of them have been channelized for timber floating (straightening and narrowing, removal of boulders and alteration of in-channel habitat diversity).

Score of pressure level imposed on small, single-thread, mid altitude rivers categorised according to pressure category and pressure, respectively (score in comparison to other pressures within this river type: No = no pressure/stress, L = low pressure/stress, M = moderate pressure/stress, H = high pressure/stress).

Pressure category	Pressure	Score
Point sources	Point sources	M to H*
Diffuse sources	Diffuse sources	M to H^{+}
Water abstraction	Surface water abstraction	L
	Groundwater abstraction	L
Flow alteration	Discharge diversions and returns	L
	Interbasin flow transfer	No
	Hydrological regime modification including erosion due to increase in peak discharges	M
	Hydropeaking	No
	Flush flow	L
	Impoundment	M
Barriers/Connectivity	Artificial barriers upriver from the site	H
	Artificial barriers downriver from the site	M
Channelization	Channelisation / cross section alteration (e.g. deepening) including erosion due to this	H
	Sedimentation	M
Bank degradation	Bank degradation	H
Habitat degradation	Alteration of riparian vegetation	H to M^{-}
	Alteration of in-channels habitat	H
Others	Maintenance	M
	Exotic species	L

*differs between regions, high in e.g. Eastern Europe, moderate in e.g. Central Europe
$^{+}$high if fine sediment input is substantially increased, moderate if only nutrient loads are increased
$^{-}$differs between regions, high in Central Europe, moderate in boreal rivers

Problems and constraints for river restoration

Bank fixation limits (lateral) channel dynamics which naturally would be high due to the relatively high stream power.

In free flowing sections, bed substrate coarsens and armouring layers develop due to the high flow velocities in the narrowed and deepened cross-sections. This is especially a problem in gravel-bed rivers with a wide range of grain sizes (poorly sorted substrate), which are prone to develop armour layers. Moreover, the interstitial spaces are filled with fine sediment eroded from non-forested clear-cuts, agricultural areas or trampled river banks. Alternating bars and associated pool-riffle sequences are rare due to the low channel width and sediment deficit caused by upstream barriers. This results in a (non-natural) stable plane-bed morphology. Sediments are packed, coarse, and clogged with fine sediment. Due to the armour layers, bed-material is only mobilized during very high flow events and hence, natural sediment- and morphodynamics are limited. In addition, the lack of large wood results in a uniform channel morphology and uniform high flow velocities and water depth.

In impounded sections, coarse sediment is deposited, causing a sediment deficit downstream. Moreover, also fine sediment is accumulated and in addition to the low flow velocities does not provide any habitat for typical species inhabiting fast-flowing gravel-bed rivers.

Furthermore, missing riparian vegetation reduces the input of organic matter (e.g. leaves, large wood), which is easily transported downstream due to the limited retention capacity of the uniform cross-section. Moreover, missing riparian vegetation reduces shading, resulting in higher water temperatures and increased temperature dynamics.

Measures

Common restoration practice

Most of the restoration projects in small, single-thread, mid altitude rivers applied in-channel measures to increase habitat complexity (~80%), most frequently by removing bed and bank fixation and adding large wood and boulders. Many projects did also aim to restore a more natural planform (~40%) by e.g. remeandering or developed a riparian buffer strip (~30%), while measures to explicitly restore natural sediment dynamics (e.g. by adding sediment, restoring natural sediment transport or limiting fine sediment input) are very rarely applied (~1%).

Score per measure category/measure of relevance, effect in-channel, effect on the floodplain and costs the measure in comparison to other measures within this river type (No = no relevance or effect, L = low relevance or effect, M = moderate relevance or effect, H = high relevance or effect of the measure) and indication a prioritisation of measures (L = low priority, M = moderate priority, H = high priority).

Measure category	**Measure**	**Relevance**	**Effect in-channel**	**Effect floodplain**	**Costs**	**Prioritisation**
Decrease pollution	Decrease point source pollution	M	M	L	H	M
	Decrease diffuse pollution input	H	H	M	H	H
Water flow quantity	Reduce surface water abstraction	L	L	L	L	L
	Improve water retention	M	M	H	H	M
	Reduce groundwater abstraction	L	L	L	M	L
	Improve water storage	M	M	M	H	L
	Increase minimum flow	M	M	M	H	M
	Water diversion and transfer	L	L	No	L	L
	Recycle used water	L	L	No	L	L
	Reduce water consumption	L	L	No	L	L
Sediment quantity	Add/feed sediment	H	M	L	M	H
	Reduce undesired sediment input	M	M	L	M	M
	Prevent sediment accumulation	No				
	Improve continuity of sediment transport	M	M	No	M	M
	Trap sediments	No				
	Reduce impact of dredging	L	L	No	L	L
Flow dynamics	Establish natural environmental flows	M	M	M	M	M
	Modify hydropeaking	No				
	Increase flood frequency and duration	L	L	M	H	M
	Reduce anthropogenic flow peaks	M	M	L	H	M
	Shorten the length of impounded reaches	L	L	No	M	L
	Favour morphogenic flows	M	M	L	M	M
Longitiudinal connectivity	Install fish pass, bypass, side channels	M	H	No	M	M
	Install facilities for downriver migration	L	M	No	M	L
	Manage sluice, weir, and turbine operation	No				
	Remove barrier	M	M	L	M	M
	Modify or remove culverts, syphons, piped rivers	L	L	No	M	L
In-channel habitat conditions	Remove bed fixation	M	M	No	M	M
	Remove bank fixation	M	M	L	M	M
	Remove sediment	L	L	No	M	L

Measure category	Measure	Relevance	Effect in-channel	Effect floodplain	Costs	Prioritisation
	Add sediment (e.g. gravel)	M	M	No	M	M
	Manage aquatic vegetation	L	L	L	M	L
	Remove in-channel hydraulic structures	L	L	No	M	L
	Creating shallows near the bank	L	L	No	L	L
	Recruitment or placement of large wood	H	H	L	M	H
	Boulder placement	L	L	No	M	L
	Initiate natural channel dynamics	H	H	M	L	H
	Create artificial gravel bar or riffle	M	M	No	M	M
Riparian zone	Develop buffer strips to reduce nutrients	H	H	H	M	H
	Develop buffer strips to reduce fine sediments	H	H	M	M	H
	Develop natural vegetation on buffer strips	H	H	H	M	H
River planform	Re-meander water course	M	M	L	H	M
	Widening or re-braiding of water course	L	M	M	H	L
	Create a shallow water course	M	M	M	H	M
	Narrow over-widened water course	L	L	L	M	L
	Create low-flow channels	L	L	L	M	L
	Allow/initiate lateral channel migration	H	H	L	L	H
	Create secondary floodplain	M	L	M	H	M
Floodplain	Reconnect backwaters, oxbow-lakes, wetlands	M	L	M	L	M
	Create backwaters, oxbow-lakes, wetlands	L	L	M	M	M
	Lower embankments, levees or dikes	L	L	M	M	L
	Replace embankments, levees or dikes	L	L	M	M	L
	Remove embankments, levees or dikes	L	L	M	M	L
	Remove vegetation	L	L	H	L	L

Problems and constraints with common restoration practice

In general, instream measures in gravel-bed lower-mountain rivers have a higher and positive effect on aquatic organism groups like fish and macroinvertebrates compared to pure planform measures. Especially the placement and recruitment of large wood is an effective restoration measure, e.g. compared to boulder addition to increase macroinvertebrate richness and fish abundance. Moreover, removing bed- and bank fixation can initiate natural channel-dynamics in these rivers with relatively high stream power, leading to a fast increase in habitat diversity. Therefore, the approach to mainly apply instream measures to restore instream habitat complexity is supported by recent research findings. The effect of restoration is especially high in catchments with a relatively high share of forested areas, probably because water quality is usually high in forested catchments (water pollution and fine sediment not constraining restoration effects), riparian vegetation is present and has beneficial effects on biota (e.g. large wood input, shading), and source populations are present to colonize the restored habitats.

However, variability of restoration effects is high and several projects had no or even negative effects. For example, large wood and boulder addition had very limited or no effects in forested river sections where large stable substrate was already present (e.g. in boreal rivers in Fenno-Scandinavia). Moreover, heavy machinery was often used which might have detrimental effects like the substantial reduction of bryophyte biomass in boreal rivers. Furthermore, even moderate water pollution and fine sediment input as well as missing source populations might limit restoration effects. Most important, the underlying processes resulting in natural flow and sediment dynamics are rarely restored, which limits the effects of locally restoring forms. As mentioned above, a low channel width and sediment deficit hinders the formation of alternating bars and associated pool-riffle sequences. Such natural flow and sediment dynamics are necessary to sustainably provide loose and clean well-sorted gravel, e.g. as habitat for invertebrates and spawning gravel for fish.

Promising and new measures

The effect of local instream restoration measures in small, single-thread, mid altitude rivers can potentially be improved by (i) ensuring that catchment-scale pressures do not constrain the effects, and (ii) restoring natural flow and sediment dynamics, i.e. processes.

The most important catchment-scale pressures which potentially constrain the effects of local restoration projects are water pollution, fine sediment, and missing source populations. If present, these pressures should be addressed in addition to restoring local habitat conditions.

- There is empirical evidence that even moderate organic pollution might still limit biota, especially macroinvertebrates, and hence, saprobic indices should indicate a good or high status.
- Source populations can be identified based on information from monitoring sites, species distribution models or expert knowledge. Based on present knowledge on fish dispersal, source populations should be at a maximum distance of about 5 km up- or downstream of the restored section. Fish dispersal models have recently been developed to assess the re-colonization potential for different fish species in detail (e.g. FIDIMO). For macroinvertebrates, source populations should be located upstream since they are less mobile than fish and purely aquatic invertebrates (hololimnic species) mainly disperse by downstream drift. Moreover, source populations should be located less than 1.0 - 2.5 km upstream of the restored sections.
- Several methods are available to quantify the fine sediment content and oxygen depletion in gravelly sediments (e.g. freeze-cores, infiltration bags, dissolved oxygen logger). There are also less labour-intensive and costly methods available for a rough assessment of fine sediment stress like (i) visual estimates of percentage cover, (ii) the shuffle index (assessing the degree and duration of reduced visibility above a white tile placed on the river bed caused by the plume resulting from disturbing the sediment upstream), and (iii) the nail test (length of rusted part of nails placed in the sediment indicating well oxygenated conditions and grey parts oxygen depletion). Moreover, some biological metrics have recently been developed indicating fine sediment stress.

Restoring forms like gravel bars has very limited effects and is not sustainable if the underlying processes which rejuvenate these channel features have not been restored as well. To ensure that alternating bars and associated riffle-pool sequences develop and persist, it is necessary to restore an adequate channel-width, natural sediment loads and dynamics, and a natural flow regime. If the present channel-width is too low to allow the formation of free stable alternating bars, the non-natural plane-bed morphology will even persist if natural sediment transport has been restored. Therefore, it is crucial to first restore a natural channel width. Methods to asses if the present low channel width constrains the formation of free stable alternating bars are described in literature. Second, if there is a sediment deficit, river continuity for sediment transport has to be restored or - at least - sediment has to be continuously added to mitigate the sediment deficit. Third, the flow regime must not be substantially altered e.g. by increased peak flows from impervious areas.

Monitoring scheme

Monitoring schemes should follow some basic principles that apply to all river types:

- Biotic as well as abiotic variables should be monitored. The restoration measures might have succeeded to create the desired habitats but the effect on biota might be limited due to other pressures at larger scales which have not been addressed in the restoration project.
- In-channel, riparian, as well as floodplain conditions should be monitored. Besides the biological quality elements relevant for the Water Framework Directive, restoration can also have positive effects on other semi-aquatic and terrestrial organism groups, like ground beetles and floodplain vegetation. Indeed, there is empirical evidence that effects on other organism groups can be larger.
- Monitoring has to be conducted at appropriate spatial and temporal scales that reflect (i) the habitat needs of the organisms (e.g. monitoring microhabitat substrate patches for macroinvertebrates, mesohabitat features for fish, consider habitats at river margins and in floodplain like side channels and ponds), (ii) all life stages (e.g. monitoring in-channel and riparian habitats for macroinvertebrates with terrestrial life-stages), (iii) the reproductive cycle as well as dispersal abilities (long-term monitoring to also cover effects of restoration on long-lived species and weak dispersers), and (iv) seasonal changes and patterns that occur during the year.
- Looking at the spatial and time scale of many current restoration measures macro-invertebrates are most suited for river monitoring. Fish population are strongly managed and reflect larger scale conditions, macrophytes bear a long history as they disappear only slowly and algae reflect to short time scales and very, very local conditions. Floodplains are large scaled and best be monitored by vegetation. Riparian zone can be monitored by using vegetation or carabid beetles.
- A Before-After-Control-Impact design should be applied to allow disentangling the effect of restoration from general trends in the whole river or catchment.
- However, the final selection of the organism groups, and spatial / temporal scales monitored strongly depends on the objectives and applied measures. Of course, it is reasonable to focus on the abiotic and biotic variables and scales that potentially have been affected by the restoration measures (e.g. in-channel habitat conditions by in-channel measures).
- Monitoring results should be used for adaptive management, i.e. to react on unanticipated effects and trends, and this should be included in the planning from the beginning ("Plan-B").

For further reading and practical guidelines we refer to the handbook of the River Restoration Centre (River Restoration Centre 2011).

The relevance of a variable at the scale of the river, riparian zone and floodplain scored in comparison to other variables within this river type (No = no relevance, L = low relevance, M = moderate relevance, H = high relevance)

Variable group	Variable	River	Riparian zone	Floodplain
River hydrology		H	M	M
In-channel hydraulics		H	M	No
Floodplain morphology		L	L	M
In-channel morphology	Profile (longitudinal, transversal)	H	M	M
	Meso-/micro-structures	H	L	No
Chemistry	Nutrients	H	M	L
	Toxicants	H	M	L
	Others			
Biology	Algae	L	No	No
	Macrophytes	M	L	No
	Macroinvertebrates	H	L	No
	Fish	H	L	No
	Floodplain/riparian vegetation	L	M	M
	Terrestrial fauna	No	M	L