7 Hydromorphological pressures in rivers

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7.1 Introduction

With the word 'hydromorphological pressures' we understand all changes caused by human influences to either the flow regime (hydrology) or the morphology of the stream that affect the biota. The most important hydromorphological pressures are:

- building of dams or weirs for hydropower, water supply or other purposes
- canalization and/or dredging of rivers or streams to improve drainage or for navigation
- weed cutting to improve drainage
- abstraction of water directly from the stream or from groundwater for water supply or irrigation, or diversion (e.g. for hydropower or irrigation).

Other influences that are not described in detail here include urbanisation, afforestation/deforestation, draining of wetlands (tiling), transport and supply of water from outside the river basin to increase river discharge at dry periods, and high discharges of water treatment plants in small river basins.

7.2 Dams and weirs

The term 'impoundment' is often used to describe any structure that alters river water levels. Larger height structures (often termed dams) are built to provide a hydraulic head to generate electricity (hydropower) and to store water for irrigation and water supply. Smaller height structures or weirs are built to maintain water levels in low flow periods for agriculture, shipping and recreation and to divert water for supply, hydropower or irrigation. Depending on the height of the impoundment, the upstream physical environment will change, increasing depths and retention times and decreasing velocities, with major effects on the ecosystem. Impoundments can also disrupt the connectivity of the river, alter the flow regime and lower the sediment transport downstream. Flushing flows may be used to clean out fine sediment from the reservoir and downstream river bed, and can also re-structure the bed generally.

Usually river sections downstream of dams have lower and less frequent floods than the natural flow regime (Growns and Growns, 2001), although more extreme floods are often unaffected. The resulting less variable flow regime and lower sediment transport often leads to higher water temperatures and clarity. Large dams generally lower the temperature downstream, when cooler water is drawn from the hypolimnion of the impounded reservoir. Another typical feature of rivers downstream of hydropower stations are daily and weekly flow fluctuations depending on hydropower pricing. The physical changes also lead to changes in water chemistry.

Plants and animals are affected by the physical and chemical changes. The higher clarity and reduced variability of flow usually leads to a higher abundance of periphyton and higher plants (Dessaix and Fruget, 1995; Biggs *et al.*, 1998). In nutrient-rich rivers the occurrence of phytoplankton is usually increased downstream of the dam as a result of phytoplankton production in the reservoir. Benthos communities below dams often show a reduction in species richness, while some species increase in abundance (Fruget, 1991). For example, invertebrate filter feeders (e.g. Hydropsychidae, Simulidae) often increase in numbers downstream of reservoirs. Migratory fish (e.g., salmon, trout and eel) are especially affected by the breaking of the connectivity of the river. The spreading of other animal groups and plants can also be hampered because of the reservoir (Allan, 1995).

Methods for evaluating the ecological consequences of damming

The ecological consequences of a damming of a river are generally large because the river ecosystem is changed into a lake ecosystem where the reservoir is established. Descriptions of the ecological impacts therefore include both a comparison of the reservoir ecosystem with the original river ecosystem and a description of the ecological consequences of the created river discontinuity. The ecological consequences of weirs are usually smaller and can often be assessed by the same methods as used for assessment of other changes in river morphology.

7.3 Changes in river morphology

Canalization and dredging

Rivers and streams are canalized for purposes such as navigation, flood protection, drainage of agricultural land and urbanisation. For example in Finland, some rivers have been straightened and narrowed to facilitate transport of logs downstream. The straightening of meandering streams or rivers is often combined with a recurrent dredging of deposited material to maintain the desired river profile. Canalization changes a naturally meandering stream with hydromorphological variety into a uniform channel with homogeneous bed substrate and relatively uniform water velocity across the stream. The channel is usually constructed to be wider than the natural profile to allow for a larger conveyance, and the water depth and velocity will decrease. Often the flow variability and the light conditions at the streambed will be affected as well.

These physical changes cause a reduced variety of habitat and consequently a lower species richness of the stream flora and fauna compared with undisturbed streams (Hortle and Lake, 1983; Allan, 1995; Dessaix and Fruget, 1995; Giller and Malmqvist, 1999). Many stream invertebrates are adapted to a life on coarse substrates (stones and gravel) with high current velocities. Also, the availability of fish spawning habitats is dramatically reduced in rivers that are canalized and dredged because of the removal of stones and gravel.

Weed cutting

Weed cutting is undertaken in many small and medium sized streams to increase the discharge capacity and prevent the surrounding areas from inundation. River vegetation is rarely found deeper than 1.5-2 metres and weed cutting is thus a phenomenon related to smaller streams. When weeds are cut, the water level drops and the water velocity increases, which again may increase the sediment transport and temperature. Bank stability may also be reduced. However, the physical changes and the impacts on the river ecosystem are strongly dependent on the weed cutting method.

The immediate effect of weed cutting is a direct loss of plants, which serve as a habitat for invertebrates and a refuge for fish. The lower water level also reduces the available space and the habitat diversity. Long-term use of weed cutting changes the composition and structural complexity of the macrophyte community, which becomes poorer in species and spatially more homogeneous. Also, substantial changes in composition patterns can develop with an enhanced abundance of fast-growing species with a high dispersal capacity (Baattrup-Pedersen *et al.*, 2003). A reduced diversity and structural complexity of macrophyte communities can affect invertebrate and fish communities negatively. This probably relates to a lower spatial and temporal physical heterogeneity i.e. less varied substrate composition and more narrow range of flow velocities with decreasing structural diversity of the macrophyte community (Garner and Bass, 1996). Therefore loss of macrophyte species and homogenisation of communities as a result of weed cutting may have cascading effects on the whole stream biota.

Methods for evaluating the effects of changes in river morphometry

Morphological classification systems. It is useful for the implementation of the WFD to characterise streams according to their morphology. This morphological characterisation should be targeted to be a causal link between the anthropogenic pressure on the river morphology and the resulting impact on the river biota.

Different methods and indices are used in different countries.

- The Austrian Habitat Survey (Werth, 1987; Muhar *et al.*, 1996; Muhar *et al.*, 1998) in Austria
- The Danish Stream Habitat Index (Pedersen and Baattrup-Pedersen, 2003) in Denmark
- The SEQ Physique (Agences de l'Eau and Ministère de l'Environment, 1998) in France
- The Ecomorphological Survey for Large Rivers (Fleischhacker and Kern, 2002) in Germany
- The River Habitat Survey (RHS) (Raven *et al.*, 1998) in the UK.

The methods use a number of parameters (channel, bank, floodplain, flow-related) and a scoring system to evaluate the hydromorphological status of streams. Most of these methods are based on a pseudo reference condition, which is identified on the basis of a top percentage of sites according to their habitat quality scores. This causes a problem for the type of rivers of which there are only few, or few with no impacts (e.g., large rivers).

Fish indicators. The occurrence, density and reproduction of fishes in streams are very much influenced by the stream hydromorphology. The FAME project[1] developed fish-based metrics sensitive to various pressures, including hydromorphology.

[1] http://fame.boku.ac.at.

7.4 Abstraction and diversion of water

Water is abstracted from streams and rivers for water supply or irrigation, rivers are diverted for various reasons, and sometimes streams are augmented by water from other catchments to increase the stream flow for agricultural purposes. In the case of abstraction, water is taken either directly from the stream, in which case the flow is reduced immediately, or it is taken from groundwater and will affect the stream flow, depending on the distance of the borehole from the stream and the hydraulic properties of the sediments between the borehole and the stream. Often the highest demand occurs in summer, when the flow is naturally low. Thus, the most important effect of abstractions is on the low flow regime, while diversions are more likely to affect the stream at all times. Reducing the flow will lead to lower depth and velocity and an increase in temperature (especially in summer), and the dilution of pollutants will reduce. In some cases when water is diverted or abstracted, the stream may even dry up completely.

A reduction in flow caused by abstraction, or diversion, affects the biota (e.g. Collier, 2002). Usually the growth of filamentous algae is favoured (mainly due to lower velocities) and the invertebrate community will change from one that grazes on thin periphyton films to one that lives amongst thick periphyton mats. Amphibious plants may invade more central parts of the stream from which they are normally kept away by high velocity and depth, and the distribution of plant species will change. Reduced water level and velocity leads to a loss of river habitat, which may affect biota on all levels.

Methods for the evaluation of changes in flow regimes

Flow criteria. The most well known classification system based on natural, frequently historical, flows is the Tennant method (Tennant, 1976), sometimes also called the Montana method, which specifies that 10% of the average flow is the lower limit for aquatic life and 30% of the average flow provides a satisfactory stream environment. The Tennant method was based on hydraulic data from eleven U.S. streams (including streams in Montana) and considerations of what values of velocity, depth and width were needed for sustaining aquatic life, with a focus on fish.

Historical flows can also be used to define 'an ecologically acceptable flow regime', although one should be careful to distinguish between pre-development historical flows and impacted historical flows, which may over a period of time have altered the composition of biota. Arthington *et al.* (1992) describe a 'holistic method' that considers not only the magnitude of low flows, but also the timing, duration and frequency of high flows. Such a flow regime would not only sustain biota during extreme droughts, but it would also provide the high flows and flow variability needed to maintain the diversity of the ecosystem.

Habitat models. Habitat models describe relationships between the water discharge and the biota of a river reach. Most habitat models use preference indices, which determine how suitable a given quality element (velocity, depth, substrate) is for certain species and their individual developmental/ life history stages. These models then combine the results from hydraulic models with the preference indices to produce values of river area weighted by habitat quality (weighted usable area) as a function of flow for a given species and life stage.

Current software includes:

- PHABSIM (Physical Habitat Simulation; Bovee, 1982; Milhous *et al.*, 1989), and RHABSIM (River Habitat Simulation) used in the United States
- RHYHABSIM (River Hydraulics and Habitat Simulation; Jowett, 1989) used in New Zealand
- EVHA (Evaluation of Habitat; Pouilly *et al.*, 1995) used in France
- CASIMIR used in Germany (Jorde, 1997)
- RSS (River Simulation System; Killingtviet and Harby, 1994) used in Norway
- HABITAT used in the Netherlands (Duel *et al.*, 2003).

Habitat Suitability Indices (HSIs). Physical HSIs allow relation of habitat preferences for a given species and life stage to hydraulic parameters such as velocity, depth and substrate. An example is given in Figure 7.1. Most HSIs have been defined as univariate response functions but more complex multivariate relationships also exist (Parasiewcz and Dunbar, 2001). The relationships established by HSIs are useful for decisions on the protection of relevant habitats or on the restoration of habitats.

LIFE Index. The LIFE index (Lotic Invertebrate index for Flow Evaluation, Extence *et al.*, 1999) was formulated to test whether it is possible to link changes in benthic invertebrate community structure with indices of historical river flow at a gauge close to the sample site. The LIFE index can be calculated from species or family-level bio-monitoring data. Each taxon is assigned a velocity preference from I to VI (based on literature data), and five abundance categories are used. Implicit in the 'velocity' preference is preference or avoidance of silty substrates. A matrix is then used to give a combined score for each taxon in the sample of between 1 and 12. The scores for all taxa are added together, and the average score is the LIFE index.

It is important to note that the index is expected *to* be sensitive to natural and artificial flow changes; it thus allows an extrinsic hypothesis to be tested. Extence *et al.*, 1999, demonstrated that correlations exist between the LIFE score and moving averages of historical flows (e.g. Figure 7.2). LIFE is currently being used in England and Wales as part of the implementation of Catchment Abstraction Management Strategies and the Water Framework Directive (Soley *et al.*, 2002; Dunbar *et al.*, 2004). The LIFE index is also being examined in the STAR project and its sensitivity to flow tested (Dunbar and Clarke, 2004).

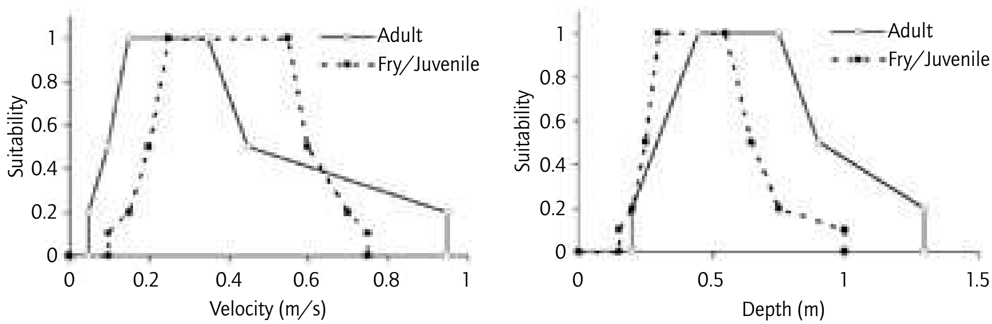

Figure 7.1 Habitat suitability indices for two developmental stages of brown trout (from Bird *et al.* 1995).

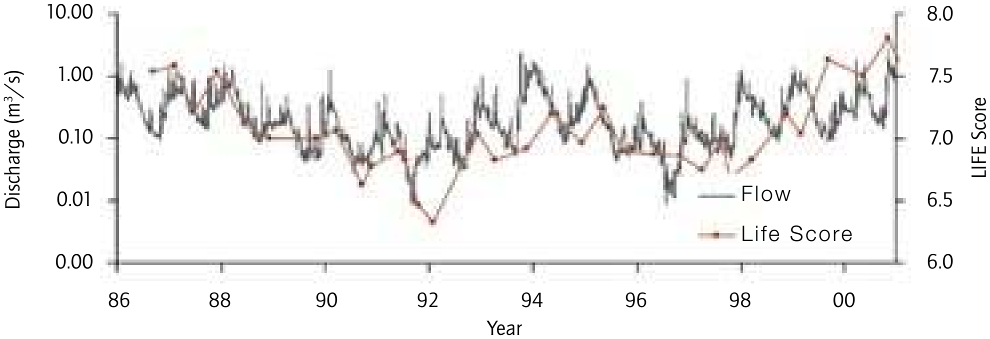

Figure 7.2 Flow and the LIFE score in the Waithe Beck in the UK (data from Extence et al., 1999).

Mean flow rank index. A similarly constructed index (MFR – mean flow rank) has been developed by the Environment Agency of England and Wales to relate flows to macrophyte communities (Soley *et al.*, 2002).

7.5 Summary

Damming, water abstraction, channelisation, dredging and weed-cutting cause major hydromorphological pressures on river ecosystems. The ecological consequences of damming are generally well known: A river reach is changed into a reservoir and the river continuity is broken. The ecological consequences of water abstraction and of changes in river morphometry (channelisation, dredging, and weed cutting) are known to some extent. However, this knowledge is not sufficient to establish operational relationships between the degree of pressure (the extent of anthropogenic impact) and the impacts on river biota needed for the implementation of the Water Framework Directive (WFD).

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