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Causes of failure and success of lowland stream restoration

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Abstract
Over the last decades millions of euros were allocated to lowland steam recovery, and hundreds of streams were actively restored. An evaluation of restoration projects showed comparable results. What is worrisome is that the majority of the projects evaluated very rarely monitor elements of stream biota directly to assess restoration success. Those project where recovery is monitored often fail to show success. Partly, this failure is due to incomplete restoration whereby only certain disturbances were tackled while others not. Partly, failure is due to dispersal barriers preventing re-colonisation. Success on the other hand are often due to either large scale approaches or to within catchment circumstances.

Introduction

Lowland streams are characterised by a gentle slope of the terrain (zero to five per mill) and a sandy soil. They occur in the flat lowland areas of the Western European plain. Lowland streams are fed by rainwater; they often lack a well-defined source. Thus, their discharge shows a smoothed relation with the amount and frequency of precipitation in the various seasons. Their current velocity varies from 5-30 cm s^{-1} in summer and early autumn and from 30-60 cm s^{-1} in late autumn to spring. Often the rainwater fed upper courses dry up in summer, though sometimes they are fed by a helocrene spring and then show a more constant discharge pattern (Verdonschot, 1990).

After a long time-period of adapting lowland streams and their catchment to agricultural, domestic, drinking water and industrial needs, one became aware of the damages of these alterations. For example, in the Netherlands only about 4% of the streams still have a natural hydromorphology. The last ten years, the ecological importance of streams became more and more apparent.

Nowadays, stream restoration is one of the answers to the lowland stream deterioration. In order to make the proper choices in stream restoration; one firstly has to understand the complex spatial and temporal interactions between physical, chemical and biological components. The success of restoration depends on steering the appropriate key factor(s). Which factor this is, differs for each stream and each site. The most important stream ecology concepts are those concerning dimensions and hierarchy. Ward (1989) introduced the concept of the four dimensional nature of stream ecosystems with a longitudinal, lateral, vertical and temporal component. The major idea was the attempt to identify the controlling processes functioning in a stream as integral part of a catchment. Frisell *et al.* (1986) ordered the controlling factors from catchment to stream habitat in a hierarchical space and time framework. Knowledge of this hierarchy allows us to infer the direction and magnitude of potential changes (alteration as well as restoration) due to human activities.

But theories on stream ecology are complex and not easy to use in the practice of stream management. This appears from an evaluation of a large number of surveys about stream restoration. The main problem in stream restoration is the daily conflict between the theory of an approach of the integrated whole versus the limited practical possibilities on the square meter.

Stream managers need a simple decision support system to handle the ecological complexity for an effective restoration plan at a site. This manuscript provides such a system. It gives the opportunity to go trough the most important steps in stream restoration and to extract the factors in the catchment that should be tackled. Each site and each stream is different. But the approach of planning a successful restoration should be the same. The decision support system is based on the theories of dimensions, scale and hierarchy and forces a water manager to include the catchment in the restoration plan.

This paper discusses in section one the stream ecology concepts. Section two deals with the experiences with stream restoration. The third is based on the knowledge available in the concepts on stream ecology, comprised in the 5-S-model (Verdonschot *et al.* 1998) and combines these with the daily practice and experiences of stream management.

Theoretical concepts in stream ecology

Concepts

Ecosystems are composed of groups of interacting and interdependent parts (e.g. species, resources) linked to each other by the exchange of energy and matter. Linkage not only occurs between different parts in the transversal profile of a stream but also between upstream and downstream parts of a stream. For a long time, the longitudinal component of a stream was seen as a sequence of inter linked zones (Illies & Botosaneanu, 1963; Hawkes, 1975) or as a longitudinal continuum (Vannote et al., 1980; Wallace et al., 1977). But exchange of energy and matter is not limited to the stream itself. Hynes (1975) was the first one who included the catchment. Stream ecosystems are considered to be complex because their functioning is not limited by the stream itself and the banks but it stretches out all over the catchment. Within the catchment as a whole, streams are characterised by strong interactions between components, feedback loops, significant interdependencies in time and space, discontinuities, thresholds, and limits (Costanza et al., 1993). To entangle this complexity, Ward (1989) introduced the concept of the four dimensional nature of stream ecosystems with a longitudinal, lateral, vertical and temporal component (Figure 1). Except from this theory about dimensions a second theory is important. This theory concerns hierarchy. Processes in streams are important at different scales. The organisms in a stream are dependent on habitat characteristics. These characteristics are in their turn dependent on morphology and hydrology of a stream. Morphology and hydrology depend on geomorphologic structure and climate in the catchment. Beside the dimension and scale theories some other concepts on streams should be taken into account when dealing with lowland streams. The most important concepts on stream ecology are summarised in Tale 1.

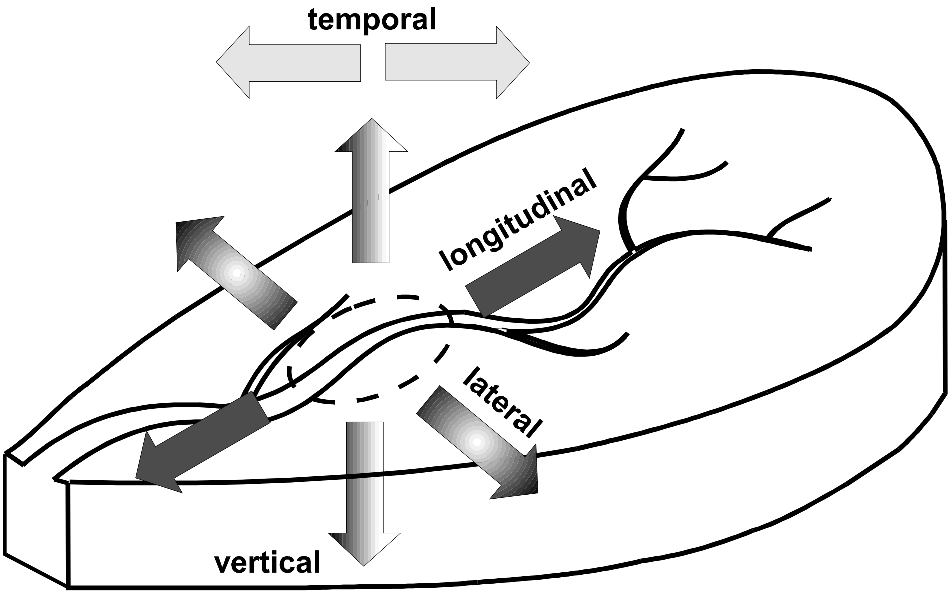

Figure 1. The concept of the four dimensional nature of stream ecosystems with a longitudinal, lateral, vertical and temporal component (Ward 1989).

Table 1. Some characteristics of major ecological concepts in stream ecology.

Ecological Concept	**Key theme**	**Direction**	**Scale**	**Reference**
	Dimensions			
Four dimensional nature of lotic systems	longitudinal, lateral, vertical and temporal exchange	longitudinal, lateral, vertical, temporal	Catchment	Ward 1989
River Continuum Concept	longitudinal gradient	longitudinal, lateral	stream, floodplain	Vannote et al. 1980
Nutrient Spiralling Concept	longitudinal nutrient cycling	longitudinal, lateral	stream, floodplain	Wallace et al. 1977
Flood Pulse Concept	lateral exchange of substances	lateral, temporal	lower reach, floodplain	Junk et al. 1989
	Hierarchy			
Hierarchy	**hierarchy and**	top – down and bottom - up	fine to coarse	Frissell et al. 1986
	Response of species			
Dynamic Equilibrium Model	dynamic equilibrium in systems	conceptual, temporal	independent	Huston 1979
Intermediate Disturbance Hypothesis	non equilibrium maximises diversity	conceptual, temporal	independent	Ward & Stanford 1983a
Habitat Template Concept	r, k, a selection in space and time	spotwise	stream section	Southwood 1977
Patch Dynamics Concept	competition versus disturbance	spotwise	stream section	Townsend 1989
	Human influence			
Serial Discontinuity Concept	discontinuity through human interference	longitudinal	stream	Ward & Stanford 1983b

Stream catchment in four dimensions

The overall concept “the four dimensional nature of lotic systems” identifies in general terms all interactions and functioning of the stream as an integral part of the catchment (Figure 1).

1. The **longitudinal** component covers the whole catchment. There are important upstream-downstream linkages in the stream as well as in the catchment as a whole. The functioning of a lowland stream strongly depends on the input, transport and finally output of water. Water moves downstream and transports energy and matter. There are different longitudinal zones as shown in Hawkes (1975), the river continuum concept of Vannote et al (1980) and the Serial Discontinuity Concept of Ward & Stanford (1983b) of which the latter two stress the importance of the stream as a continuum with or without discontinuities, respectively. All these concepts imply a more or less gradual shift in abiotic stream characteristics and species composition along the stream gradient. Furthermore, also the effect of downstream activities on up-stream stretches must be included in the longitudinal component. Channelization down-stream affects the discharge and erosion patterns up-stream (Schumm, 1977). A weir down-stream acts as a migration barrier and thus changes biotic components and interactions up-stream. Another important feature of the longitudinal transport of water is nutrient spiralling. This concept explains that a nutrient cycle is completed while the nutrient is transported downstream (Wallace et al., 1977).
2. The **lateral** component includes the whole of interactions transversal through the catchment and covers the floodplain. The lateral component concerns the interaction within and between stream, riparian zone, floodplain and catchment. The interactions in-stream concern turbulence in the water column and erosion-deposition processes in the a-symmetric transversal profile. The interactions between stream and riparian zone got more and more attention in the last decennium (Petersen et al., 1987; Naiman & Décamps, 1990). The stream – floodplain interaction is amongst others described in the Flood Pulse Concept (Junk et al., 1989). The interactions concern exchange of silt and substances through direct surface and sub-surface runoff but also exchange of biota through inundation and migration
3. The **vertical** component concerns the soil beneath and the air above the stream. The vertical component stresses the groundwater-surface water interaction (Brunke & Gonser, 1997), expressed in the hyporheic zone (Stanford & Ward 1988). The latter zone is of little to no importance in lowland streams. The vertical interaction also includes the exchange processes between stream and air. Processes of exchange such as evaporation, deposition of substances (e.g. Kristensen & Hansen, 1994) and biotic interactions. Some animals use the atmosphere for movement in the adult phase of their life cycle (reproduction, dispersion).
4. The **temporal** component includes changes in time. The temporal component includes processes going on, such as the length of the organisms life histories, morphological changes in meander patterns over long periods of time or abrupt changes through channelization (Boon, 1992). Also within a stream, the processes in time and space are conceptualised, such as in the patch dynamics concept (Townsend, 1989). But the temporal component should also include historic developments (Kondolf & Larson, 1995).

A catchment approach includes all four dimensions

This concept could be used as a frame for an integrated catchment management. The transport property of a stream is the most important process and directly depends on the catchment (spatial component). Because of the open character of the stream, it reflects the past and present structure and functioning of the whole catchment and thus includes the temporal component. Water that infiltrates in the catchment can have a long retention time before it enters the stream. In a catchment approach the longitudinal and transversal components also include the 'dry' floodplain and the (infiltration) areas at a higher altitude in the catchment. In fact, infiltration areas affect the stream water quality and land use in these areas influence, amongst others, transport of substances towards the stream. The deep groundwater flow, which connects infiltration areas to the streams, is important in lowland streams and differs in the different reaches. Upper courses often only receive subsurface and less deep flow, middle reaches can receive subsurface flow but are also often infiltrating, lower reaches almost always receive deep, old groundwater. The water enters the stream in a more vertical direction as seepage. In conclusion, a stream is part of its catchment and can not be studied without looking along these four dimensions.

Scale and hierarchy

Large watersheds are comprised of tributaries and their catchment, tributaries contain multiple stream reaches, each reach potentially includes different habitats, and these habitat each contain multiple microhabitats (Frissell et al., 1986; Sedell et al., 1990). The multitude of processes that form stream systems exist within a hierarchical framework (Allan & Starr, 1982; Frissell et al., 1986). The hierarchy theory provides a framework for the description of the components of an ecosystem and their scaled relations (O'Niell et al., 1986, Jensen et al., 1996).

The four dimensions in streams concern aspects of spatial and temporal scale and hierarchy (Figure 2). The temporal component is not always independent from the spatial ones and can be added to each of them.

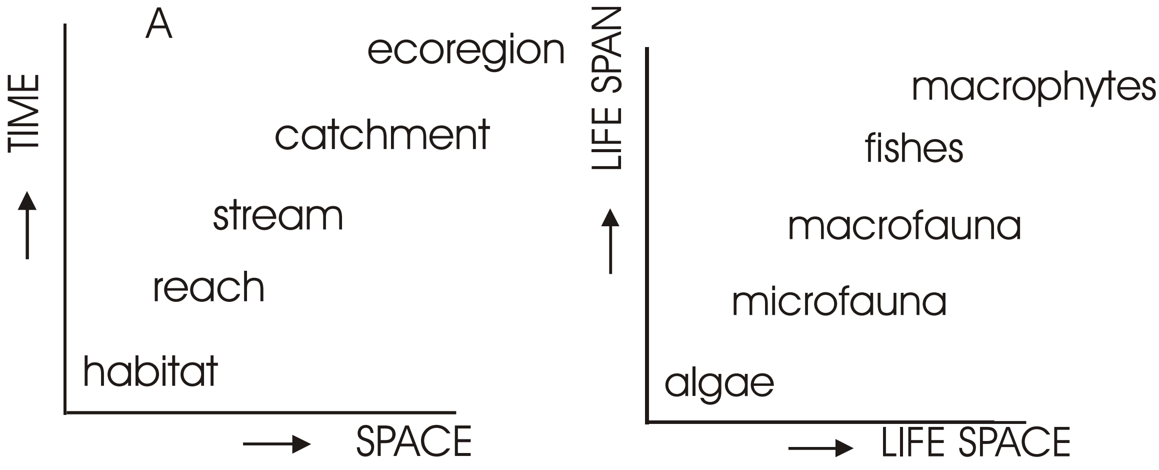

Figure 2. Spatial and temporal scale and hierarchy (A), and the response scale of different taxonomical groups (B) (after Verdonschot 1999).

The longitudinal component stretches out over the whole spatial area of the catchment. It more often concerns processes acting over a long-term period, such as deep groundwater flow and processes of longitudinal meandering. But there also examples of shorter term like nutrient spiralling and fish migration. The longitudinal component can be related to a coarse spatial and a different temporal scales.

The lateral component interacts at the spatial scale of the flood plain and concerns processes like inundation and (sub-) surface runoff. These interactions more often act over a shorter time period. The lateral components also include the creation and evolution of oxbows or marshes; they act over a long term. Thus, the lateral component can be related to an intermediate spatial and again different temporal scales.

The vertical component includes the riparian zone or the wooded bank as well as the thin more or less oxygenated substrate layer on the stream bottom. Its interactions more often cover a short time period such as the exchange of gasses between atmosphere and water column, the emerging and reproduction of adult insects in the overhanging trees or the (bio-)turbation of the stream bottom substrate. On the other hand the vertical component is highly influenced by processes that operate at a long temporal scale, such as erosion and deposition resulting from stream incision. The vertical component can be related to fine spatial and different temporal scales.

A catchment approach acts at different scales and includes hierarchy

There is a hierarchy between the three components in space and time whereby the longitudinal component (coarser scale) bounds the range of ecological features of the lateral and vertical ones (finer scales), but also the vertical one (finer scales) affects the lateral and longitudinal components (coarser ones). Stream functioning acts at multiple spatial and temporal scales with ‘top down’ and ‘bottom up’ controls often termed dominance and feedback.

Integrated ecological approach in stream restoration should include more than one spatial (include at least one lower scale) and temporal scale (to include system dynamics) dependent on the objective which is addressed. Looking at stream functioning always should cover a fine, intermediate and coarse scale in space and time.

Including the whole catchment in stream ecology and restoration of streams implies working in hierarchical order. It is no use to start at a small scale (certain habitat in a stream) if there are problems on the large scale (in the infiltration area of the catchment). In a catchment approach processes at different scales in the catchment varying from microhabitat to catchment are included.

Lowland stream restoration in The Netherlands

Current threats

Lowland streams in the Netherlands belong to the most threatened ecosystems. About 96 % of all Dutch streams is directly impacted by human activities (Verdonschot *et al.*, 1995). It concerns changes in the length and transversal profile through channelization affecting the structures in the stream. It also concerns the discharge pattern and water level by construction of weirs and other artificial constructions, water extraction and drainage. All affect the stream hydrology. Changes in the shape and hydrology of the lowland stream leads to an increase in discharge fluctuations and an erosive character of the stream. The latter is responsible for a deep bed-incision of most lowland streams. In its turn, bed-incision is the cause of drought in the floodplain.

Thereby, direct discharge of wastes, surface runoff of agricultural land and water inlet affect the chemical composition of the water. It is estimated that 60-80 % of the in stream nutrients originate from agricultural sources while only about 10-20 % originates from discharges. Agricultural activities also affect the quality of the groundwater, a future threat of the stream environment.

The remaining 4 % of Dutch lowland streams is only near natural, indirectly affected by atmospheric pollution, groundwater extraction and changes in the catchment. All near natural stream parts are only located in the upper courses of streams.

A comparison between large data banks including macro-invertebrates and environmental variables of the eighties and nineties resulted in the following conclusions (Verdonschot *et al.*, 1995):

- The increase in drainage intensity and the management directed towards quickened discharge of water has led to a decrease in current velocities during base flows and an increase during peak flows. Furthermore, this resulted in an increase in drought especially in the floodplain (not shown). Thereby, also acidification increased.
- The upper courses showed an increase in nutrient load due to the increase in agricultural activities in the upper parts of the catchment. Most sources of nutrients are diffusely spread over the catchment.
- The middle and lower courses show a decrease in nutrient and organic load due to purification of point sources of pollution.

The overall condition of lowland streams is still deteriorating. The effect of other disturbances such as stream maintenance, deforestation and angling are still unclear.

Inquiries on stream restoration

More and more stream restoration projects are carried out in the Netherlands. In 1991, 1993, 1998, 2003, and 2008 inquiries were made to describe the state of stream restoration in the Netherlands. In 1990/91, the Agricultural University of Wageningen conducted an evaluation of technical stream rehabilitation (Hermens & Wassink, 1992). In 1993, 1998, and 2003 additional surveys updated these data, especially added ecological criteria (Verdonschot *et al.*, 1995; Verdonschot, 1999a). In 2008 a new full inquiry was performed. The consulted authorities were national and provincial governments, regional water authorities and nature conservation institutions. In total, 85 organizations were interviewed in 1993, 16 major ones in 1998, and 30 in 2008. The results of the restoration projects in these inquiries stretch over a time period of 1960-2008.

Stream restoration is developing fast in the Netherlands. In 1991 70 projects were counted, until 1993 170, and this number peaked in the period 1993-1998, and stabilized around 177afterwards (Table 2).

Table 2.Number of lowland stream restoration projects over four time intervals..

period	**until 1993**	**1993-1998**	**1999-2003**	**2004-2008**
total number of projects planned, in development or ongoing	125	147	75	97
total number of projects finished	45	59	101	82
total	170	206	176	179
average number of projects planned, in development or ongoing	-	25	15	19
average number of projects finished	-	10	20	16

average	-	34	35	36

Mostly, stream restoration projects were integrated projects in which national and regional authorities and water and nature managers co-operated. The latter took care of choices of concrete measures and execution.

In foregoing periods (before 2004) most stream restoration projects concerned upper and middle courses. Recently (2004-2008), the number of projects in middle courses even increased further (50%), while the number in upper courses decreased (Table 3). As there are many more upper then middle courses, the risk of receiving stress from upstream in such stretches is realistic. In 22% of the projects larger stretches are restored. But the Total number of projects that include the whole stream is decreasing (Table 3). Again such tendency is not preferred in catchment oriented stream restoration.

Table 3. Percentage of projects finished per stream course (n(2004-2008)=149).

stream course	until 1993 (%)	1993-1998 (%)	1999-2003 (%)	2004-2008 (%)
spring	3	0	0	2
upper course	18	32	27	14
middle course	27	36	30	50
lower course	24	18	7	11
spring and upper course	2	7	0	1
spring, upper and middle course	3	0	0	3
spring to lower course	3	18	0	1
upper and middle course	6	17	11	9
upper to lower course	8	0	18	1
middle and lower course	5	11	7	7

In Total, recently 663 km stream course, with an average of 4 km is restored (Table 4). Compared to the 17000 km of streams in the Netherlands this is about 4%. Restoration thus still takes only a very small part of the streams. Most stream length is restored in the middle course, 286 km, which corresponds to the higher number of projects in this course (Tab3, Table 44). Hereafter, lower courses (72 km) and upper courses follow. The average stream length per project restored increase from spring (0.7 km) down to the lower course (4.3 km).

Table 4. Total and average stream length (km) per stream course.

stream course	total in Netherlands (km)	average per project (km)
spring	2	0.7
upper course	69	3.3
middle course	286	3.8
lower course	72	4.3
spring and upper course	1	0.6
spring, upper and middle course	21	4.2
source to lower course	15	15
upper and middle course	60	4.6
upper to lower course	9	9.0
middle and lower course	46	4.2
not specified	80	6.2
total	663	4.1

Measures

Three-quarters of all measures applied belonged to the category of 'hydrology and morphology' (37%), or 'land-development' (37%) (Table 5). Recently, measures related to hydrology (linking parts of the former catchment (30%), drainage (51%), and groundwater level rise (44%) became more important. Remeandering and reprofiling covered 80% of all measures undertaken, an strong increase in comparison to before 2004 (up to a maximum of 50-60%). The development of inundation zones (40%) and the removal of weirs (31%) did since 1999-2003 increase again. In about one quarter of all projects a new streambed was dug. This is often combined with reprofiling and improvement of the riparian zone. This indicates that valley wide restoration is growing.

The measures from the category 'Land-development', less use in foregoing years, creating an asymmetrical profile (70%), low gradient banks (80%), and improvement of fish migration paths (80%), became more important. In comparison to 1999-2003 more nature friendly banks were constructed (27%). Development of riparian zones is increasing, and nowadays takes almost half of all projects. Measures that are becoming more and more in use (up to 16%) are creating steep and overhanging banks, creating sand banks and stream bed pits, and active development of micro-meandering.

'Maintenance measures' took 17% of all measurement, and 'Water quality' took 9%. The relatively minor attention for maintenance measures indicates that the profits are still undervalued. Though in many projects (91%) maintenance became less intense, additionally supported by nature friendly maintenance of stream banks (40%). Nature friendly maintenance of the stream bed and the use of grazers to maintain water plants were applied in about 25% of all projects. Stream valley wide measures (one third of all projects) referred to changes in land-use and dig of nutrient rich soil in adjacent riparian zones.

Table 1. Planned and realized stream restoration measures (n(2004-2008)=88). n.i. = not indicated.

hydrology and morphology	**until 1993 (%)**	**1993-1998 (%)**	**1999-2003 (%)**	**2004-2008 (%)**
link parts of the former catchment	n.i.	n.i.	n.i.	30
remove drainage	21	32	4	23
heighten the drainage basis	n.i.	n.i.	n.i.	51
heighten the groundwater level	n.i.	n.i.	n.i.	44
relocate, decrease or stop groundwater extraction	n.i.	n.i.	n.i.	0
remeander, passive development	0	21	5	5
remeander, active creation	38	57	37	80
reprofile (more shallow and narrow bed)	7	46	13	80
install hydrological buffer	0	21	8	13
promote infiltration	0	32	4	7
develop inundation zone	17	36	23	40
dig bypass	3	21	10	3
dig new streambed	n.i.	n.i.	n.i.	25
reinstall (original) catchment	0	25	5	5
link old meander	4	25	8	0
open long culverts	n.i.	n.i.	n.i.	0
increase water retention/storage	14	54	33	39
install weir	n.i.	n.i.	n.i.	2
remove weir	14	29	10	31
split water paths agriculture-nature	n.i.	n.i.	n.i.	3
change/reduce water extraction	3	7	6	0
re-use purified effluent	0	4	0	n.i.
reinstall former streambed	n.i.	n.i.	7	n.i.
develop wood/wooded bank/forest	14	36	12	n.i.

land development	**until 1993 (%)**	**1993-1998 (%)**	**1999-2003 (%)**	**2004-2008 (%)**
create asymmetrical profile	0	36	10	70
create low gradient banks	n.i.	n.i.	8	80
create isolated pools	0	46	22	30
create nature friendly banks	n.i.	n.i.	7	27

create winter shelters for fish	n.i.	n.i.	n.i.	16
create wet banks	n.i.	n.i.	n.i.	22
create pool, one-sided linked to the stream	n.i.	n.i.	n.i.	2
create steep and overhanging banks	3	18	3	16
create streambed pits and sand banks	4	0	1	16
create two phase profile	38	21	17	8
remove bank stabilization	17	25	12	14
develop/plant wood in banks	45	43	30	48
active develop micromeanders	0	14	4	16
create wet environments	n.i.	n.i.	n.i.	33
introduce obstacles in the stream	17	4	3	3
improve fish migration paths	31	50	18	80
create species specific structures	0	4	2	n.i.

water quality	**until 1993 (%)**	**1993-1998 (%)**	**1999-2003 (%)**	**2004-2008 (%)**
create buffer zones	7	21	10	18
create helophyte filters	7	4	2	2
split waste paths	7	18	4	0
clean and re-use effluent	n.i.	n.i.	n.i.	0
dig of nutrient rich soil in adjacent riparian zones	3	32	15	32
reduce inflow with nutrient/organic enriched water	10	21	6	7
change land use	n.i.	n.i.	n.i.	33
stop Household discharges	7	18	3	2
reduce/stop water intake	n.i.	n.i.	n.i.	2
reduce/stop inflow contaminants	n.i.	n.i.	n.i.	16
reduce/stop sewage overflow	14	18	10	3
improve sewage treatment plants	0	4	2	3
clean underwater soil	n.i.	n.i.	2	0
create horse-shoe wetland	0	4	1	n.i.
reduce micropollutants	7	19	1	n.i.

maintenance	**until 1993 (%)**	**1993-1998 (%)**	**1999-2003 (%)**	**2004-2008 (%)**
active biological maintenance	n.i.	n.i.	n.i.	1
natural water level management	n.i.	n.i.	n.i.	14
introduce grazing	n.i.	n.i.	n.i.	24
less intense maintenance	n.i.	n.i.	n.i.	91
dredge in phases	n.i.	n.i.	n.i.	0
species specific structure measures	n.i.	n.i.	n.i.	9
nature friendly maintenance streambed	n.i.	n.i.	n.i.	25
nature friendly maintenance banks	n.i.	n.i.	n.i.	40
nature friendly maintenance riparian zone	n.i.	n.i.	n.i.	17
fish friendly management of weirs, sluices, dams, and so on	n.i.	n.i.	n.i.	3

others	**until 1993 (%)**	**1993-1998 (%)**	**1999-2003 (%)**	**2004-2008 (%)**
reintroduction species	10	7	1	1
create fauna tunnels (dispersal routes)	n.i.	n.i.	1	n.i.

Monitoring

Monitoring is needed to evaluate effects of measures taken in streams. Recently (2004-2008) about 80% of all projects included monitoring, which is a decrease in comparison to foregoing periods (98%). Monitoring, both before and after the measures were taken, was reported in 20% of all projects. Of about 30% of all projects monitoring was done but the parameters included aren't (Table 7).

The monitoring of macroinvertebrates and water quality parameters reduced strongly over the last four years (Table 7). On the contrary, fish monitoring was doubled.

Table 2. Monitoring of stream restoration projects (n(2004-2008)=88). n.i. = not indicated.

biotics	**1999-2003 (%)**	**2004-2008 (%)**	**2004-2008 (before and after) (%)**
macroinvertebrates	80	27	15
phytobenthos	0	9	2
fish	20	40	26
macrophytes	47	36	25
bank vegetation	18	25	20
amphibians	7	n.i.	n.i.
Odonata	13	n.i.	n.i.
birds	9	n.i.	n.i.
abiotics			
hydrological parameters	42	34	32
(hydro)morphological parameters	22	28	9
water quality parameters	76	26	19
contaminants	n.i.	10	10
unknown	n.i.	30	0

The importance to monitor both before and after the measure(s) were undertaken is not recognized. This could improve both learning from doing and increase knowledge on effects. Only monitoring before was more frequent in comparison to only monitoring after. This indicates that knowing restoration is needed was more important then evaluating the effects of improvement.

Effects

The effects of all measures undertaken were hard to evaluate. Most responders did not answer to these questions or provided only general answers.

Most effects of measures were judge as positive, especially morphology and fish migration paths. The effects on water quality seem limited to absent.

Also foregoing inquiries showed that evaluation lacked. Further, it is doubtful whether judgments were base don data analyses.

Table 3. Effects of restoration measures (n(2004-2008)=77).

effect	**positive (%)**	**negative (%)**	**no effect (%)**
physical-chemical quality	1	0	29
current velocity conditions/variation	47	0	0
morphology	65	0	0
conditions for specific species	23	1	0
spatial coherence	19	0	0
water storage/retention	18	0	0
permanence	14	0	1
fish passages	62	0	1
natural vegetation development	16	0	0
stream swamp development	1	0	0
general additional effects	30	0	0
unknown	16	16	16

Causes of failure and success

Most of the causes of failure and success were only mentioned once by the responders (Table 9). This provides only a scattered overview of the common experiences.

Still, major causes of failure and success that could be extracted were:

Failure

1. Stream restoration is performed at a local scale.
2. Stream restoration tackled only one or few environmental conditions.
3. Stream restoration ignored the riparian zone and the stream valley.
4. Stream restoration focused on one organism group and forgot about the ecosystem as a whole.
5. Stream restoration ignored dispersal potentials and barriers.
6. Stream restoration targets were not specified.
7. Lack of communication hindered stream restoration.
8. Stream restoration was based on historical geography and forgot about current environmental conditions.
9. Different measures in stream and valley served opposite objectives.
10.

Success

1. Stream restoration should be integrated, include the whole stream and stream valley.
2. Stream restoration is embedded in intrinsic landscape/catchment processes.
3. Stream restoration needs a clear and open communication between participants and be base don a well described, detailed common approach.
4. A solid monitoring of stream restoration is needed urgently.
5. Stream restoration becomes more successful when brought in balance with other land use functions and human activities (e.g. recreation).
6. Targets of stream restoration must be clear, described in detail, relate to the process of the landscape and be communicated to stakeholders.
7. Stream restoration can not be generalized but needs specific adaptations per catchment and stretch.
8. Stream restoration needs time to reach ecosystem recovery.
9. Include aspects of maintenance into account in the stream restoration planning process.

There were very few comments on effects of specific measures. Despite the recognition of the importance of monitoring and evaluation, few projects were really monitored before and after the measures were undertaken.

Table 4. Notes (based on comments of 11 responders) that support future stream restoration, divide in positive and negative items.

indication	**ecology**
positive	the stream ecosystem often responded fast and unexpected, but mostly positive
positive	removal of local drainage systems caused less risks and brought more profits, restoration potential was often much larger, and risks for acidification appeared smaller
positive	colonization evolved faster
positive	wider riparian zones offered higher biodiversity, heterogeneity and gradients
positive	all developmental stages in communities are equally interesting, final stage develops after 5-7 years
positive	wooded banks did *Juncus* beds disappear (shading)
negative	fish was negatively affected by decreasing the streambed, take care and remove large fish
negative	phosphorus was released a long time after measures were taken
negative	colonization did not occur
negative	shallow streams were overgrown with helophytes

neutral	be open to stream swamp development
neutral	eutrophication is strongly underestimated
neutral	water plant development was hard to predict
	process/approach
positive	include an ecologist in the planning process
positive	it is not about mathematics but creating optimal environmental conditions as a starting point
positive	the effects of stream restoration appear positive in the first years, and in general improvement goes on for even more then ten years after
positive	plan on the basis of a solid system analysis and let the stream be part of the valley
positive	integrated approach (quality and quantity -> e.g. trophy) is a must to reach success in stream restoration and prevent failures
positive	communication with stakeholders created goodwill and potential but took time
positive	include other land use functions like recreation
negative	do not start taking measures before the planning process is finish
negative	communicate
negative	targets must be specified in detail
negative	monitoring and evaluation is needed before continuing taking the same measures
negative	policies should be consequent and communicated with stakeholders
negative	lack of communication hinders restoration
negative	harmonize ecological views
negative	plans did not take maintenance and monitoring into account
neutral	link plan and performance sometimes lacked
neutral	only start when all land needed can be developed
neutral	planner should be involved in performance
neutral	learn for doing, monitor and evaluate
neutral	work together
neutral	available space is crucial
neutral	contradictions in policies like water quantity vs water quality vs nature conservation must be clear
neutral	monitor
neutral	evaluate the development and adjust if necessary
neutral	link target, plan, performance and maintenance
	morphology/hydrology
negative	forgot to include hydrology, geography, drainage and side streams
negative	forgot about hydrology (urban area)
negative	to small profile caused maintenance costs
neutral	inundation zones were needed but could not be realized
neutral	adapt to current not to historical conditions
neutral	ecologists must be included in the design of the hydromorphology
neutral	lowland streams are wide and shallow
neutral	streams run over the lowest parts of the valley
	others
positive	local people enthusiastic about attractiveness restored stream
positive	each stream is unique, each stream restoration project also
neutral	have the guts to try
neutral	keep the amount of sand transported just after taking measures into account
neutral	stream restoration is stream specific

Final remarks

The joint management of land and water within the entire catchment to ensure stream integrity is emerging as a response to the recognition of increasing degradation of stream systems (Allan *et al.*, 1997). Much of the rationale for stream catchment management derives from the idea that a catchment is a topographically and hydrologically defined unit; the catchment approach (Hynes, 1975). The hierarchical organisation of the catchment is recognised (Frissell *et al.*, 1986). However, there is limited understanding of the relative importance of local versus regional versus supra-regional factors. Certain processes are likely to be primarily under local control while others depend on factors acting over larger areas. As an example, studies on buffer strips showed that riparian zones are important to the stream and their width buffers the influence of the human activities in the catchment (Osborne & Kovacic, 1993). Thus, land use becomes less important relative to riparian land use (Allan *et al.*, 1997). Remains the question about the relative importance of local versus regional, and catchment wide influences on the stream ecosystem. Roth *et al.* (1996) and Allan *et al.* (1997) concluded that local and riparian conditions are important but that regional landscape conditions may be of greater importance.

Boon (1992) added a fifth dimension to Ward's 'four dimensional nature of lotic systems'. This fifth dimension is conceptual and addresses basic questions of philosophy, policy, and practice; thus questions on 'why', 'what' and 'how' from the societal point of view. Also Naiman *et al.* (1992) argued for a new perspective on catchment management that recognises the need to find a balance between ecological, economic and social values within a long-term framework of sustainability and human use. This meets a number of problems such as different governmental authorities to work together and a co-ordination of spatially and temporal autonomic developments in human use.

A more multi-disciplinary approach is needed based on the principles of a catchment approach. Human uses, economic and societal values are part of integrated catchment management. Only in such a way catchment can be managed sustainable.

It is evident that such conservation and management programmes must include an understanding of the basic ecological processes responsible for the origin and maintenance of organisms, habitats and landscapes. One of the first concerns of stream ecosystem rehabilitation projects based on ecological processes must be the integrity of the water system (Tockner & Schiemer, 1997). Restoration of the flow regime is one of the most neglected aspects in stream restoration (Henry & Amoros, 1995, Verdonschot *et al.*, 1998).

To implement such integrated ecological assessment we need to (Verdonschot, 1999):

(a) describe stream ecosystems in a catchment context which means over multiple scales; an *ecological catchment approach*. These system description should be uniform.

(b) typify each stream in ranges of abiotic and biotic terms at different scales; an *ecological typology approach*. Types are placed named in terms of steering key factors (processes) and quantified. The potentials are described in terms of target (standard) and reference conditions.

(d) recognise all human activities in the catchment whereby the impact on the stream type is quantified; a *societal approach*. The latter asks for knowledge on cause-effect relationships.

These items together offer a framework over multiple scales stream restoration.

The implementation of these needs means the necessity of techniques to describe, develop, monitor, asses, evaluate and test; knowledge on cause-effect relationships; techniques to survey, prioritise, predict, aggregate and split; techniques for trend-analysis and knowledge- and expert systems. One should not forget the coherency between these tools. The whole of tools should be supported by a standardisation of techniques and methods, a communicative presentation and a well thought public relations.

In final conclusion, integrated ecological stream restoration is not always everything everywhere. Though it is a catchment approach, it does not mean to know everything of the catchment but to know everything of the ecologically relevant interactions within the catchment in relation to the stream system functioning. Stream restoration above all concerns interactions (ecological connectivity). It supports sustainable stream management, which needs not only to restore but also to monitor, evaluate, predict, assess et cetera. The ecological methods chosen are always objective dependent but should imply multiple scales and cover the catchment relationships. The choices are taken 'bottom up' and use the advantages of existing knowledge and tools. Furthermore, a multiple scale and multidisciplinary approach always asks for co-operation.

To support such approach and based upon all measures evaluated a list of measures improving stream ecosystem quality was described (Table 10) and included in a decision support sheme (Figure 3).

Table 10. Actions and stream restoration measures.

ACTION	RESTORATION MEASURES
A restoration groundwater supply and flow	removal of surface and subsurface drainage improvement of infiltration change of (ground-)water extraction forestation construction of hydrological buffers infiltration of purified effluent creation of inundation areas improvement of water retention reconstruction of natural catchment
B length profile adjustment	natural re-meandering digging new meanders construction of in-channel meanders
C profile restoration	construction of a-symmetric profile construction of overhanging banks profile reduction removal of profile consolidation removal of weirs construction of by-passes and secondary channels create berms to take high flows
D riparian zone restoration	construction of wooded banks digging of pools reconstruction/opening of old meanders lowering of adjacent land
E1 water quality improvement (non-point sources)	discharge reduction of toxic substances discharge reduction of manure and nutrients diversion of polluted flows
E2 water quality improvement (point sources)	discharge reduction of sewage discharge reduction of effluent improvement purification plants
F water purification	construction of natural purification filters (helophytes) construction of horse-shoe wetlands construction of buffer zones

G re-introduction/removal of species	removal by fishing re-introduction programmes
H maintenance adaptation	reduction of maintenance frequency reduction of maintenance intensity spotwise maintenance
I habitat improvement	measures above reconstruct habitats for individual species create riffles and pools construction of fish ladders introduce objects into the channel (trees, stones) most

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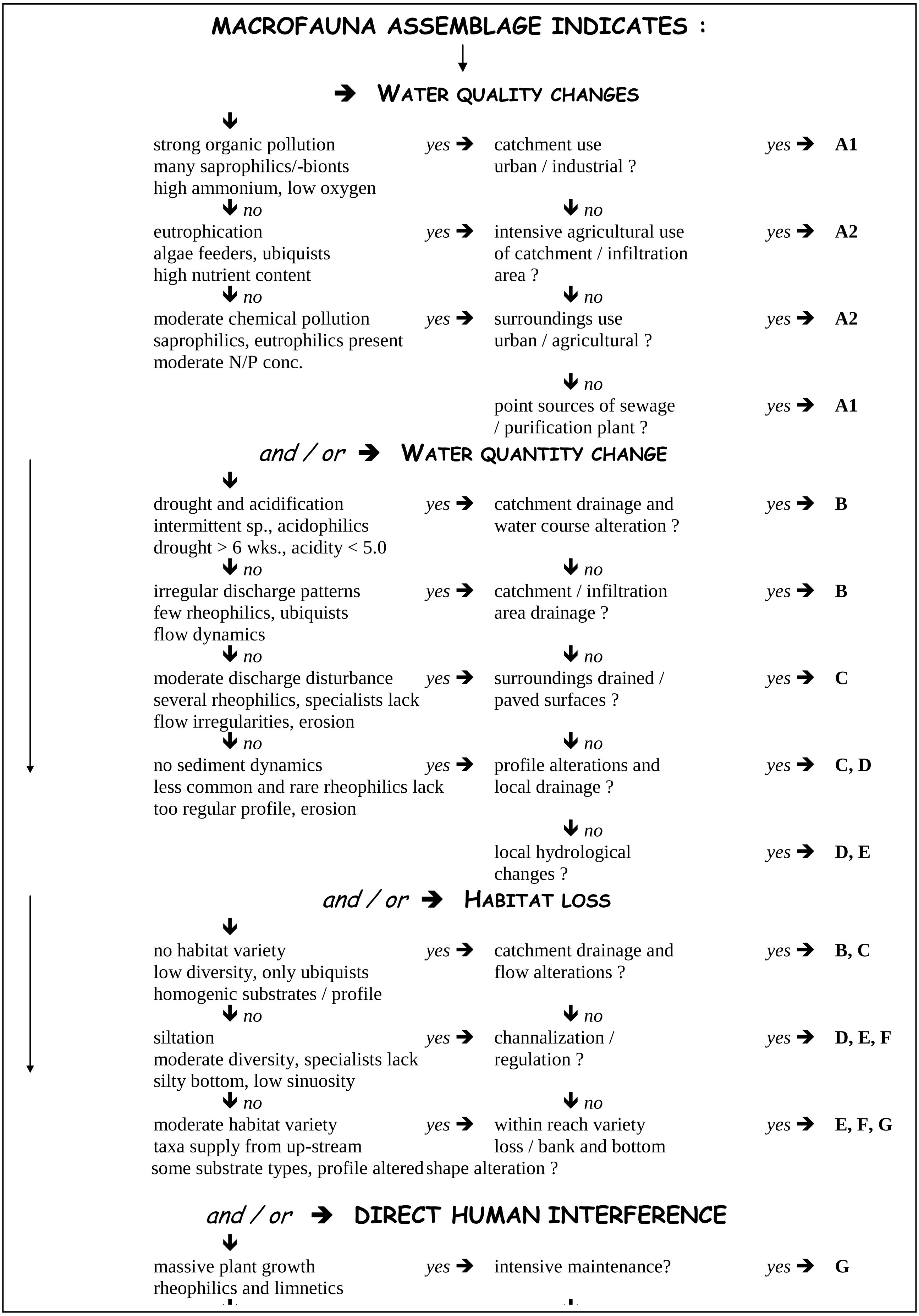

Figure 3. Decision key for stream restoration

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