doi: 10.7558/bhs.2012.ns01

Assessment of the multiple benefits of river restoration: the Logie Burn meander reconnection project

Stephen Addy, Sohan Ghimire and Susan Cooksley

The James Hutton Institute, Craigiebuckler, Aberdeen, AB15 8QH, UK
Email: Stephen.Addy@hutton.ac.uk

Abstract
River restoration has been advocated as a means of delivering multiple benefits including enhanced lotic habitat and natural flood risk mitigation to satisfy the requirements of different policy drivers (e.g. WFD, Flood Risk Act Scotland 2009). Extensive research has been undertaken to assess the physical and ecological effects of numerous kinds of active and passive river restoration. However, relatively little research has been conducted to assess the positive benefit that active restoration (e.g. re-meandering) could have for mitigating flood risk or the transfer of nutrients; such research is needed to inform the planning of river restoration in the future. A 160 m reach of the Logie Burn, a small straightened agricultural stream in Aberdeenshire, Scotland, was reconnected to old meanders that were previously sealed off from the main channel. The primary purposes of the reconnection were to restore morphology, improve river habitat, enhance riparian habitat diversity and demonstrate this type of restoration to river managers. A further desire was to reduce phosphorous transfer into Loch Davan (which the Logie Burn joins) by enhancing in-channel phosphorous storage as anticipated. A monitoring programme commenced in July 2011 to assess how the geomorphology, habitat, phosphorous storage and the flood attenuation capacity of the reach change over time. Topographical and sedimentary surveys were undertaken before and after the reconnection and will be repeated annually. In addition, stream flow is being continuously monitored to allow assessment of the flood attenuation capacity and to help understand the geomorphic changes observed.

Introduction

The number of river restoration or rehabilitation projects that seek to reverse morphological and ecological degradation has increased markedly in the last two decades (Gilvear *et al.*, 2012). Numerous evaluations of habitat and biotic response show a range of outcomes that reflect the different criteria for success, the quality of monitoring programs and the suitability of restoration type (Feld *et al.*, 2011). Aside from ecosystem recovery, river restoration has also been advocated as a means to address flooding problems naturally through enhancement of flow attenuation and flood storage (Wharton and Gilvear, 2007). Despite this, studies of the implications of restoration such as re-meandering, for flow conveyance and, in turn, flood risk remain rare (Kronvang *et al*., 1998; Sholtes and Doyle, 2011). Furthermore, the alteration of sediment transport capacity created by re-meandering could have implications for storage of nutrients such as phosphorous (P) — the variation of which has implications for P transfer and aquatic habitat (Ballantine *et al*., 2009). However, P responses to restoration activities like re-meandering have received little attention (Kronvang *et al*., 1998). Detailed study is needed to assess whether these multiple benefits are gained by different types of river restoration (Gilvear *et al.*, 2012) and to ensure that future restoration projects are underpinned by thorough scientific understanding (Downs and Kondolf, 2002).

In agricultural areas, there is a long history of river channel dredging and realignment to reduce loss of land by erosion, alleviate overbank flooding and to improve drainage. This has led to morphological degradation (Lepori *et al*., 2005) and reduced biodiversity (Palmer *et al.*, 2010). Due to the minimal energy available to drive self-recovery in such systems (Brookes, 1995) and considerable socio-economic constraints that limit catchment scale measures, reach scale intervention may represent the only option. In such cases this often involves re-meandering through the construction (e.g. Sear *et al*., 1998; Feld *et al*., 2011) or the reconnection of historical meanders to the current channel's water and sediment regimes. However, published assessments of meander reconnection projects are rare.

This paper reports on the initial hydromorphological monitoring of a reconnection project in north-east Scotland. The specific aims are to: (i) report on pre- and post-intervention channel geomorphology; (ii) explore the implications of these differences and future geomorphic change for habitat provision, flow conveyance and the transfer of nutrients.

Study area and meander reconnection

Catchment context

The Logie Burn (31.4 km^2) is a 4th order stream in the River Dee catchment (2105 km^2), that drains the western part of the Howe of Cromar and flows into Loch Davan in the Muir of Dinnet National Nature Reserve (Figure 1). Due to the subdued topography of the catchment, the valley bottom is unconfined and mantled with fluvio-glacial and alluvial deposits. There is no flow record: recent flow monitoring indicates a bankfull discharge at the study site of ~1.6 m^{3}s^{-1}. Land use in the catchment is dominated by agriculture (36%) and at higher elevations moorland (42%) and forestry (22%). The Logie Burn is rated as having poor ecological status under SEPA's waterbody classification due to diffuse sediment and nutrient inputs in addition to morphological alteration.

BHS Eleventh National Symposium, Hydrology for a changing world, Dundee 2012. ISBN: 1903741181

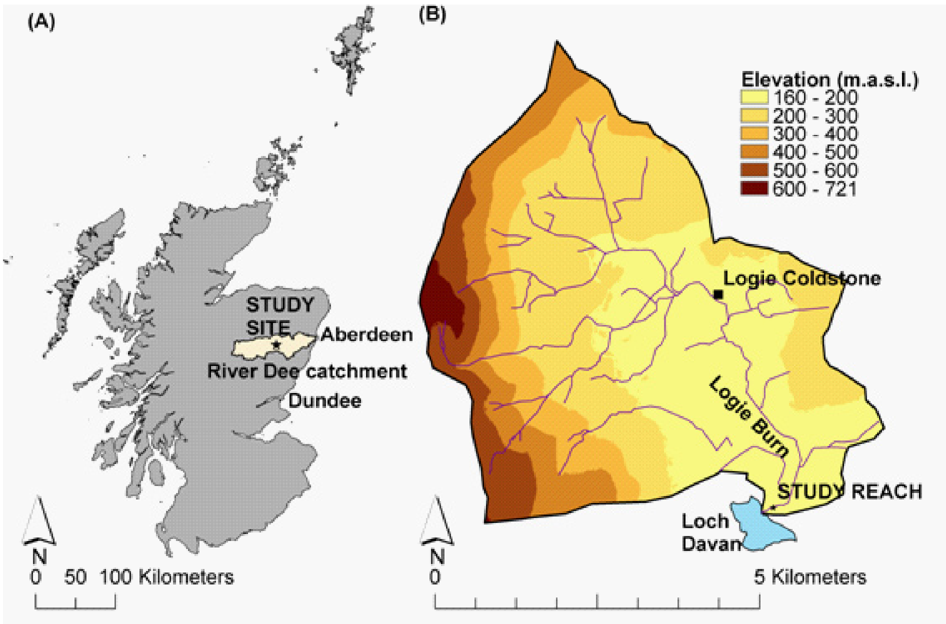

Figure 1 *(A) The location of the Logie Burn catchment and (B) catchment topography and study reach location. © Crown copyright and database right (2010). All rights reserved. The James Hutton Institute, Ordnance Survey Licence Number 100019294*

As a result of land use intensification, chronic inputs of nutrient rich sediment — principally delivered by the Logie Burn — has led to a shift in the status of Loch Davan from mesotrophic towards a eutrophic state and has reduced the lake area by ~30% over the last century (Gill and Cooksley, 2012). Recent management initiatives to mitigate these problems include the creation of buffer strips, cattle watering points and silt traps.

Reconnection reach

The 250 m long restoration project area (channel and riparian corridor) is located 120 m upstream of Loch Davan (Figure 1B). The channel is bordered by an extensive floodplain that is used for grazing. The banks are composed of cohesive fine alluvium that is well vegetated by grass and a mixture of mature deciduous trees (Figure 1B). A new straightened channel was cut in the 1960s leading to the disconnection and gradual sedimentation of the two remaining meanders.

Reconnection project approach

The reconnection project was undertaken by the River Dee Catchment Partnership who set three objectives: (1) to restore channel morphology, improve river habitat and to enhance riparian habitat diversity, (2) to reduce fine sediment and nutrient (particularly P) transfer into Loch Davan by enhancing channel sediment deposition, and (3) to demonstrate this type of restoration technique more widely.

The reconnection work was started on the 7th September 2011 and finished on the 15th October 2011. The meanders were cleared of sediment, vegetation and organic debris to allow a re-profiling of the channel cross-section with an excavator to approximate its historical form. Timber reinforced earth bunds were constructed to re-divert flow, dividing the pre-intervention channel into two backwater areas (Figure 2B). Recovered deadwood and reeds (*Typha latifolia*) were emplaced in the meanders and backwaters respectively to add diversity. Timber revetments were built

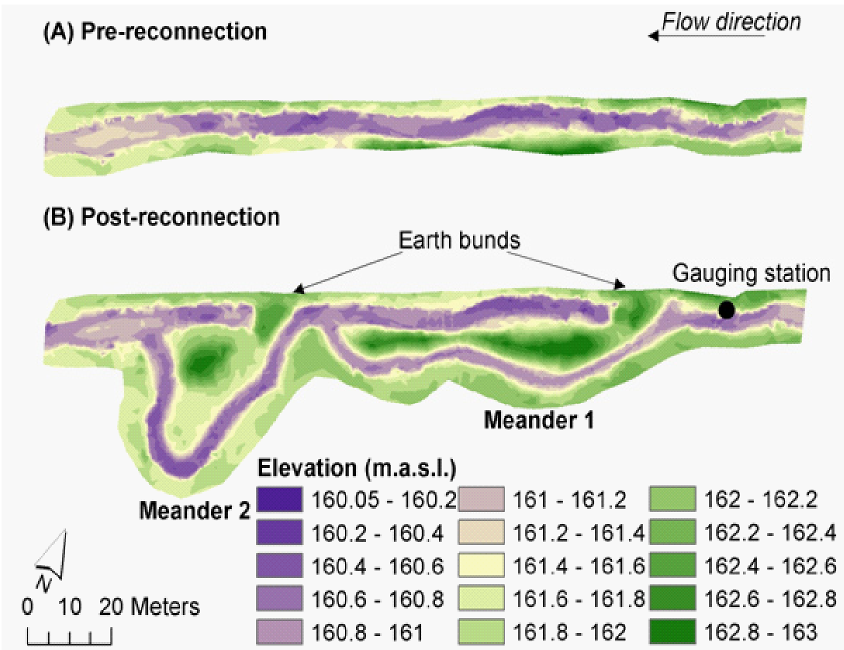

Figure 2 *(A) Pre- and (B) post reconnection DEMs of the Logie Burn study site.*

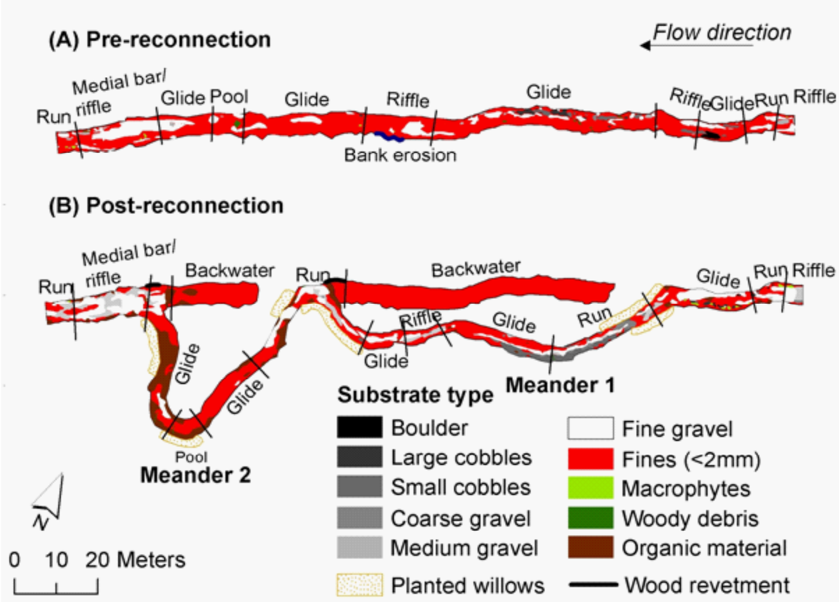

Figure 3 *The distribution of substrate types, flow types and other features of interest (A) pre- and (B) post-reconnection.*

into the north bank and willows were planted around the meander apexes to prevent bank erosion (Figure 3). In the southern area a 'scrape' was dug to create a wetland habitat and a perimeter fence was constructed to exclude cattle.

Methods

Field techniques

Geomorphic surveys were undertaken in July, August and late October 2011 to allow an assessment of the reconnection and baseline for comparison with future changes. The pre-intervention survey area was defined to include the channel sections upstream and downstream of the intervention work that would be likely to respond locally; the downstream extent was demarcated by a channel spanning woody debris accumulation. Detailed topographical surveys were undertaken using a Leica TPS800 total station (±5 mm accuracy). Survey points were taken to represent the major topographical variability of the channel and its banks. Mean channel bed point densities were 1.24 points m^{-2} and 1.91 points m^{-2} for the pre- and post-intervention surveys respectively. Morphological change in the backwater areas following reconnection were assumed to be minor, so pre-survey point data were merged with the more recent survey data. Within a ~0.5 m radius of each survey point, the dominant sediment size on the Wentworth scale and other features of interest were visually assessed to give an assessment of the substrate diversity of the channel bed. Flow type units (e.g. riffles, glides) were also mapped in the field during average flow conditions.

DEM creation and data analysis

Following conventional procedure (Heritage *et al.*, 2009), the survey point data were used to derive Triangular Irregular Network (TIN) surfaces using the 3D Analyst extension in ArcGIS 9.3 (ESRI Inc., 2008). The TINs were visually checked for errors and corrected by removing spurious point data and used to create 0.25 m resolution Digital Elevation Models (DEMs) through linear interpolation. Key geometric data of bankfull depth (d), bankfull width (w), bankfull cross sectional area (a), bed slope (S), bedform spacing (λ), bedform amplitude (α) and channel sinuosity (Si) were subsequently extracted from the DEMs. Total boundary shear stress (τ, N m^{-2}) — an index of transport capacity — was derived by using the du Boys equation:

$$\tau = \rho g d S \qquad (1)$$

where ρ is the density of water (1000 kg m^{-3}) and g is the gravitational acceleration (9.81 m s^{-2}).
To assess the potential influence of intervention on the diversity of visually identified flow type units and substrate types (H'), the Shannon-Wiener diversity index was calculated by using the following equation:

$$H' = \sum_{i=1}^{n} (P_i * \ln P_i) \qquad (2)$$

where P_i is the areal proportion of the stream bed occupied by substrate or flow type i.

Pre- and post-reconnection d and a variability were compared to allow an assessment of structural complexity (Lepori *et al.*, 2005) and flow conveyance capacity respectively. ANOVA performed on natural log-transformed data was used to test the significance of differences.

Results

Comparison of channel planform, morphology and substrate distribution shows clear differences before and after reconnection (Figure 2 and Figure 3). Notable changes to the straight reach incorporated within the new reach layout, include the alteration of flow types (Figure 3) and deposition of a thin layer of fine sediment in the newly created backwaters. Pre- and post-intervention comparison of key morphological characteristics (Table 1) shows a 31% increase in Si and a corresponding reduction of S and in turn τ in the new reach. However, despite historical channel manipulation and lower sinuosity, the previous reach exhibits slightly greater α/λ than the newly meandered reach (Table 1). This subtle bedform expression combined with the low sinuosity and evidence of bank erosion (Figure 3A), indicates the reach was actively adjusting to reinstate an incipient meandering, pool-riffle morphology. Furthermore, d variability is significantly greater pre-intervention, indicating greater bed structural complexity (Figure 4A). However this is not supported by a higher substrate diversity pre-reconnection

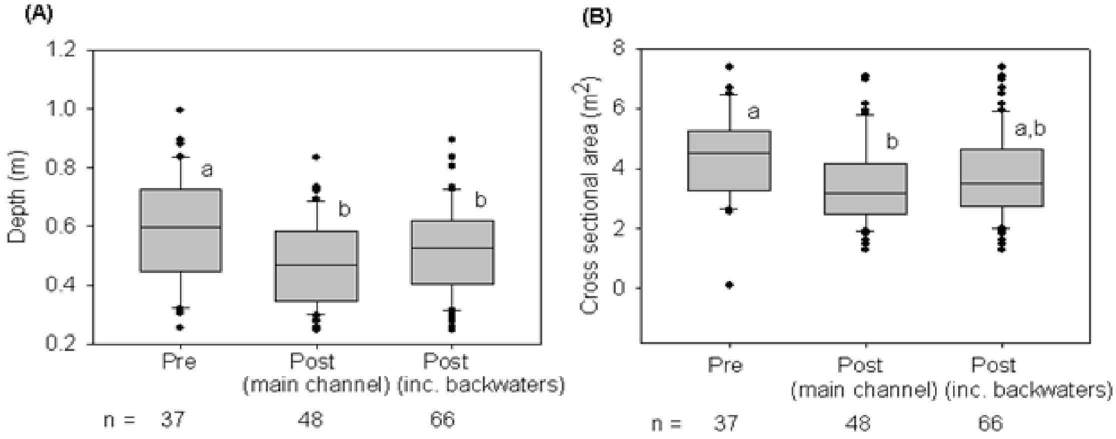

Figure 4 *Channel cross-section averages of bankfull depth (A) and area (B) for pre-reconnection, post-reconnection excluding backwaters and post-reconnection including backwaters. Different letter pairings indicate significant (p<0.05) differences using Dunn's test following ANOVA.*

Table 1 *Pre- and post-reconnection reach averaged channel characteristics (not including backwater areas).*

	Pre-reconnection	*Post-reconnection*
Channel bed area (m^2)	933.96	994.45
L [a] (m, channel widths)	187 (34)	231 (41)
S [b] ($m\ m^{-1}$)	0.0035	0.0016
Si [c] (-)	1.01	1.32
λ [d] (m, channel widths)	52.87 (9.5)	51.13 (9.1)
α/λ [e] (-)	0.013	0.011
w [f] (m)	5.56	5.63
d [g] (m)	0.6	0.48
w/d [h] (-)	10.81	12.8
τ [i] ($N\ m^{-2}$)	20.34	7.66

[a] is centre line length; [b] is bed slope; [c] is sinuosity; [d] is bedform wavelength; [e] is bedform amplitude to wavelength ratio; [f] is bankfull channel width; [g] is bankfull depth; [h] is width to depth ratio; [i] is boundary bankfull shear stress.

Table 2 *Pre- and post-reconnection substrate coverage and Shannon-Weiner diversity index (H').*

	Pre-reconnection	*Post-reconnection*
Boulders (%)	0.66	0.07
Large cobbles (%)	1.23	0.34
Small cobbles (%)	1.9	3.09
Coarse gravel (%)	0.14	1.25
Medium gravel (%)	1.44	5.56
Fine gravel (%)	18.82	15.3
Fines (<2mm, %)	75.10	62.64
Macrophytes (%)	0.23	0.34
Woody debris (%)	0.47	0.17
Organic material (%)	0	10.39
H'	0.8	1.23

(Table 2) due to a high proportion of fine (<2 mm) substrate (75.1%). In contrast, post-reconnection mapping shows a greater occurrence of coarse (>2 mm) material that is evident, particularly in Meander 1, and organic material located mostly in Meander 2 that give rise to higher diversity (*H'* = 1.23). Similarly, the distribution of flow types (Figure 3) is more diverse in the new channel configuration (*H'* = 1.48) overall compared to the original reach (*H'* = 1.15). To give an initial assessment of channel conveyance capacity, pre- and post-reconnection *a* was compared. Figure 4B shows that if backwater areas are excluded to focus on the reinstated channel, pre-reconnection *a* is significantly higher. This may reflect a legacy of historical manipulation or natural adjustment to accommodate the prevailing flow regime in contrast to the new channel configuration.

Discussion

The Logie Burn reconnection project is noteworthy as a less documented approach of using a historically meandering channel as a template to re-instigate natural geomorphic processes, forms and in turn habitats. This method seems logical given the typically long timescales of self-recovery in such systems (Brookes, 1995) and because the historical, semi-natural planform has been exploited as a target condition that existed within a human timescale. However, the extent to which any 'restored' reach adjusts towards a new dynamic geomorphic equilibrium will depend on how compliant the new morphology is with the current catchment context (Kondolf and Downs, 1996). How the new channel configuration will initiate geomorphic processes will strongly depend on how it interacts with the future upstream flow and sediment supply regimes. At the sub-reach scale, the current planform and distribution of bedforms are expected to initiate geomorphic feedbacks of erosion, especially on the outside of meander bends and longitudinal sorting of the current substrate (Knighton, 1998), resulting in a pool-riffle morphology. However, given the low transport capacity of the reach, these adjustments could be offset by aggradation and textural fining if chronic fine sediment influx exceeds transport capacity (Buffington and Montgomery, 1999).

The initial assessment of the Logie Burn restoration project suggests an improvement of the diversity of channel substrate (Table 1) and flow types (Figure 3) that may be construed as an early successful outcome that partially addresses Objective 1. Nevertheless, in comparison with the original reach, bedforms are less evident (Table 1) and structural heterogeneity as a function of depth is lower within the new channel (Figure 4A), despite the perceived degraded state of the original channel. Depending on the geomorphic adjustments projected earlier, channel and riparian habitats will also continue to evolve in parallel. For example, accentuation of the pool-riffle sequence towards that or exceeding the arrangement observed in the pre-reconnection reach, could enhance salmonid spawning habitat but could be compromised by clogging of riffles by fine sediment (Soulsby *et al.*, 2001). At this stage, it is too early to robustly evaluate whether channel habitat quality has been improved and measures of habitat heterogeneity should not be taken as a reliable indication of biodiversity due to the frequent dominance of factors such as catchment scale land use (Palmer *et al.* 2010). Other reach scale controls on ecological integrity also need to be taken into account. For example, the potential benefits of increased floodplain connectivity — a key control on channel and riparian habitat diversity (Clarke *et al*., 2003), existing and planted riparian trees (e.g. shading and food supply) and instream woody debris (e.g. cover provision and enhancement of hydraulic habitat) need to be considered.

Aside from morphology restoration and habitat enhancement, evaluation of the project also needs to consider the implications of the new channel morphology for influencing flood risk and the extent to which it addresses Objective 2. The lower capacity of the main channel for conveying flow compared to the pre-intervention reach (Figure 4B) could lead to increased frequency of overbank flooding on the low south bank (Figure 2). Coupled with the additional storage created by the backwaters and increased flow resistance due to higher *Si*, these differences could delay and reduce flood peaks downstream. Future bed adjustments to accommodate geomorphically significant flows (e.g. deepening and widening), sediment supply and increased bank roughness as vegetation cover increases will further affect response to high flows; ongoing flow monitoring will contribute to the evidence base (e.g. Kronveng *et al*., 1998; Sholtes and Doyle, 2011). The future evolution of channel flow capacity, roughness and floodplain connectivity will also have implications for the trapping of fine sediment containing P. The backwater areas, pools, floodplain, glides and channel margins are likely to act as storage zones which, combined with existing filters (in stream woody debris), could attenuate fine sediment transfer into Loch Davan. However, the benefit of such increased storage could be offset by eutrophication and consequent degradation of habitat (Ballantine *et al*., 2009); ongoing sediment sampling to ascertain total P will seek to validate these potential responses.

Conclusion

The initial assessment presented provides a useful baseline with which to compare future changes. The short period of adjustment between intervention and follow-up survey and future channel adjustment, means that a comprehensive assessment of how effectively the project meets its objectives is not yet possible. The outcome will strongly depend on the catchment scale sediment supply regime, an identified pressure that the project does not address directly and which could limit the positive responses required to address the project objectives. From a wider perspective, the monitoring contributes to the requirement of improving understanding of multiple responses to a range of different types of river restoration (Gilvear *et al*., 2012). The continued hydromorphological, bed sediment and fish monitoring will provide useful evidence for testing the efficacy of this particular project to deliver multiple benefits.

Acknowledgements

We thank Helen Watson, Leah Jackson-Blake, James Sample and Andrew Cuthbert for assistance in the field. We also thank SNH and Dinnet and Kinord Estates for their cooperation.

References

Ballantine, D.J., Walling, D.E., Collins, A.L. and Leeks, G.J.L. 2009. The content and storage of phosphorus in fine-grained channel bed sediment in contrasting lowland agricultural catchments in the UK. *Geoderma*, **151**, 141−149.

Brookes, A. 1995. River channel restoration: theory and practice. In: *Changing river channels*, Gurnell A.P. and Petts, G.E (eds),Wiley and Son. 369−388.

Buffington, J.M. and Montgomery, D.R., 1999. Effects of sediment supply on surface textures of gravel-bed rivers. *Water Resour. Res.,* **35**, 3523−3530.

Clarke, S.J., Bruce-Burgess, L. and Wharton, G. 2003. Linking form and function: towards an eco-hydromorphic approach to sustainable river restoration. *Aqu. Cons.: Mar. Fresh. Ecosys*, **13**, 439–450.

Downs, P.W. and Kondolf, G.M. 2002. Post-Project Appraisals in Adaptive Management of River Channel Restoration. *Env. Manage.*, **29**, 477−496.

Feld, C.K., Birk, S., Bradley, D.C., Hering, D., Kail, J., Marzin, A., Melcher, A., Nemitz, D., Pederson, M. L., Pletterbauer, F., Pont, D., Verdonschot, P. F.M. and Friberg, N. 2011. From natrual to degraded rivers and back again: a test of restoration ecology theory and practice. *Adv. Ecol. Res*., **44**, 119−209.

Gill, E. and Cooksley, S. 2012. Logie Burn Meander Restoration Project. Project report to SEPA Habitat Restoration Fund.

Gilvear, D.J., Casas-Mulet, R. and Spray, C.J. 2012. Trends and issues in delivery of integrated catchment scale river restoration: Lessons learned from a national river restoration survey within Scotland. *River Res. Appl*., **28**, 234−246.

Heritage, G.L., Milan, D.J., Large, A.R.G. and Fuller, I.C. 2009. Influence of survey strategy and interpolation model on DEM quality. *Geomorphology*, **112**, 334−344.

Knighton, D. 1998. *Fluvial Forms and Processes: A New Perspective.* Hodder Arnold.

Kondolf, G.M. and Downs, P.W. 1996. Catchment approach to planning channel restoration. In: *River channel restoration: guiding principles for sustainable projects*, Brookes, A. and Shields, F.D. (eds). Wiley. 129–148.

Kronvang, B., Svendsen, L.M., Brookes, A., Fisher, K., Møller, B., Ottosen, O., Newson, M. and Sear, D. 1998. Restoration of the rivers Brede, Cole and Skerne: a joint Danish and British EU-LIFE demonstration project, III—channel morphology, hydrodynamics and transport of sediment and nutrients. *Aqu. Cons.: Mar. Freshw. Ecosy.*, **8**, 209−222.

Lepori, F., Palm, D., Brännäs, E. and Malmqvist, B. 2005. Does restoration of structural heterogeneity in streams enhance fish and macroinvertebrate diversity? *Eco. Appl*., **15**, 2060–2071.

Palmer, M.A., Menninger, H.L. and Bernhardt, E. 2010. River restoration, habitat heterogeneity and biodiversity: a failure of theory or practice? *Freshw. Biol*., **55**, 205−222.

Sear, D.A., Briggs, A. and Brookes, A. 1998. A preliminary analysis of the morphological adjustment within and downstream of a lowland river subject to river restoration. *Aqu.Cons.: Mar. Fresh. Ecosy.*, **8**, 167−183.

Sholtes, J.S. and Doyle, M.W. 2011. Effect of Channel Restoration on Flood Wave Attenuation. *J. Hydr. Eng*., **137**, 196−208.

Soulsby, C., Youngson, A.F., Moir, H.J. and Malcolm, I.A. 2001. Fine sediment influence on salmonid spawning habitat in a lowland agricultural stream: a preliminary assessment. *Sci. Tot. Env.*, **265**, 295−307.

Wharton, G. and Gilvear, D.J. 2007. River restoration in the UK: Meeting the dual needs of the European union water framework directive and flood defence? *Intl. J. Riv. Bas. Manage*, **5**, 143−154.