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Short-term effects of dam removal on macroinvertebrates in a Taiwan stream

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Abstract Dam removal is an approach for restoring rivers. However, there are increasing concerns about the impact of removal on downstream biota. We examined the short-term responses of benthic macroinvertebrates and their avian predator (Brown Dipper, *Cinclus pallasii* Temminck) in reaches downstream of a check dam after it was removed from a mountain stream in central Taiwan. The density and taxonomic richness of downstream macroinvertebrates decreased immediately after dam removal. The decreases were associated with scouring or burial by sediments from the upstream impoundment. Ten weeks post-removal, downstream macroinvertebrate densities, although marginally recovering, remained lower than both pre-removal and upstream densities. Substantial changes in community structure were not significantly associated with an increase in the proportion of taxa with short life spans. However, this small-scale disturbance had no strong effect on the abundance of their very mobile, avian predator. This study and other studies of dam removal have found that downstream sedimentation following dam removal can reduce macroinvertebrate densities and that they may recover over time. Thus, timescale must be considered when interpreting the consequences of dam removal, especially when the long-term goal is stream restoration.

Keywords Aquatic insects · Dipper · Ecological response · Flood · Flow regime

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Introduction

The predictability of natural flow regimes can be a major selective force shaping the life history traits of organisms (Lytle and Poff 2004). Anthropogenic modification of flow regimes has been shown to alter the structure and function of lotic ecosystems (Poff et al. 1997). By altering flow regimes, dams can provide different social and economic benefits, including hydropower generation, agricultural irrigation, recreation, and flood control. However, dams can negatively impact the ecological integrity of lotic ecosystems (Poff and Hart 2002). River restoration can be achieved, in part, by dam removal. However, removal can cause significant short-term ecological disturbance, especially for organisms accustomed to the flow regime imposed by the dam (Hart et al. 2002).

The ecological impacts stemming from dam removal are associated with the sediment released from the former impoundment during the removal process and subsequent flash floods (Thomson et al. 2005; Orr et al. 2008). Sediments and nutrients are quickly remobilized, and the transported materials alter downstream geomorphic conditions (Skalak et al. 2009) and ecosystem processes (Stanley and Doyle 2003; Sethi et al. 2004). Most studies on the effects of dam removal have focused on fish assemblages and re-establishing their migration routes (Catalano et al. 2007). Few published studies have examined the responses of downstream macroinvertebrates.

The rapid geomorphologic changes following dam removal are associated with an immediate decrease in the density and taxa richness of benthic macroinvertebrate assemblages downstream of the dam, while assemblages upstream of the reservoir remain relatively unchanged (Thomson et al. 2005; Orr et al. 2008). One year after dam removal, downstream invertebrate density increased dramatically. This increase was associated with modification of feeding strategies (Casper et al. 2006). In addition, long-term studies, lasting from years to decades, have found changes in upstream macroinvertebrate community composition after dam removal. These changes are associated with a condition-dependent functional shift in community structure similar to those observed in the downstream communities (Stanley et al. 2002; Pollard and Reed 2004). After impounded reaches, with deep, wide channels and deposits of loose sediments, become unimpounded, the macroinvertebrate community changes from one characteristic of lentic or depositional habitats to one characteristic of lotic habitats (Stanley et al. 2002). Changes in the composition of upstream functional feeding groups following dam removal appeared to be associated with a decrease in silt coverage (Pollard and Reed 2004). One study found that community structure in downstream sites remained similar to upstream reference sites even after dam removal, because the impacts of small dam removal were minor and temporary (Thomson et al. 2005). Studies on the recovery of macroinvertebrate density and taxonomic richness following dam removal have yielded inconsistent results probably, in part, due to differences in the duration of different studies. In one study recovery was rapid over 2 months (Orr et al. 2008). However, in this study and another study, flood-mediated sediment pulses caused repeated reductions in invertebrate density and richness during the year after dam removal (Thomson et al. 2005). Even after 2–3 years, recolonization was still taking place after a massive flood associated with a dam failure in the Teton River (Minshall et al. 1983).

Downstream of the dam, there should be substantial changes in community structure associated with an increase in the proportion of *r*-selected taxa, which are characterized by small body size, a short life span, and rapid reproduction (Pianka 1970). Dippers typically prefer clear, fast-flowing streams with coarse cobble-bottom substrates (Feck and Hall 2004), and they eat larger stream invertebrates (Chiu et al. 2009). Therefore, we hypothesized that dipper abundance downstream of the dam would decrease in response to a decrease in their invertebrate prey.

We examined the stream habitat characteristics prior to and following the removal of a check dam with a sediment-filled reservoir in a montane stream in central Taiwan and documented the responses of macroinvertebrates and their avian predator, the Brown Dipper. For 3 months before and 4 months after dam removal, we assessed changes in habitat characteristics and associated macroinvertebrate responses to the removal. We predicted that dam removal immediately decreases the abundance and richness of lotic macroinvertebrates because downstream habitats are scoured or buried as sediments travel downstream.

Methods

Study sites

This study was conducted in central Taiwan in the upper part of the Dajia River, elevation 1,700–2,000 m (Fig. 1). From 1967 to 2008, annual rainfall averaged 2,071 mm and rainfall from spring monsoons to summer typhoons (May to October) averaged 1,365 mm, which often led to daily discharges greater than 10 $m^3 s^{-1}$ (Chiu and Kuo 2012). The 77 km^2 drainage area is located in Shei-Pa National Park and includes Cijiawan and Gaoshan Streams (Fig. 1).

One check dam, with a height of 16.5 m, was present within our study area in the Cijiawan Stream watershed (Fig. 1). Sediment accumulated behind the dam and eventually filled its reservoir, which had a volume of about 200,000 cubic meters. The dam was demolished and removed by excavators from May 23 to 30, 2011. A Before-After-Control-Impact design was used to study the effects of dam removal on macroinvertebrates. Two reference sites (Sites 1 and 2) were located 0.1 and 1.0 km upstream from the dam, respectively. Two "impact" sites (Sites 3 and 4) were located 0.1 and 0.8 km downstream from the dam, respectively. A tributary (Gaoshan Stream) enters Cijiawan streams between Sites 3 and 4, and Site 4 is below the confluence. The tributary contributes about 25 % of the flow discharge at Site 4 (Chiu and Kuo 2012) and could be another source of sediment or recolonization at this site. Each site was a 50 m reach of the stream channel. We monitored the habitat and macroinvertebrates at the four sites from March to September 2011. We also monitored their avian predator along each 1,850 m reach upstream or downstream from the dam during the course of the study. Data were collected 8 times at each site for habitats (4 before and 4 after dam removal), 9 times for macroinvertebrates (4 before and 5 after), and 6 times along each reach for birds (2 before and 4 after).

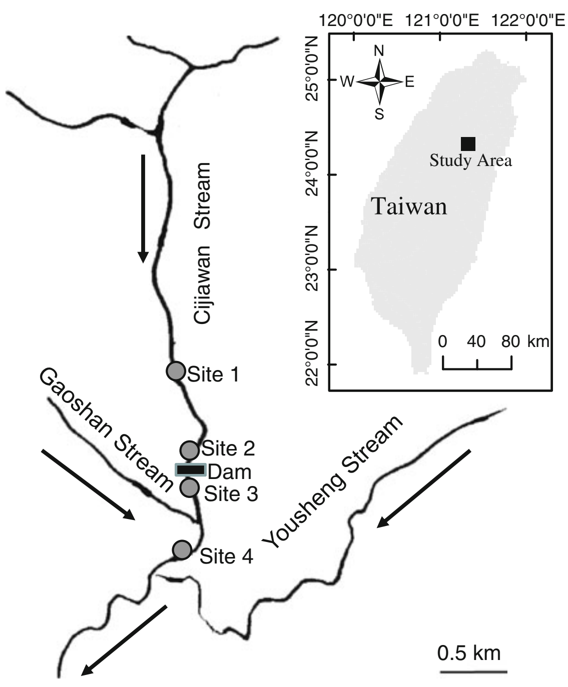

Fig. 1 Location of the four sampling sites and the check dam in the upstream drainage of the Dajia River in central Taiwan. *Arrows* indicate stream flow

Channel morphology and substrate composition

Channel surveys and channel substrate classification were used to characterize each site and assess changes in channel morphology and habitat following dam removal. Channel surveys, one of the best methods for directly assessing channel changes (Federal Interagency Stream Restoration Working Group 2001), at each of the four sites included both thalweg (the line connecting the lowest points in the stream channel) and cross sections. The survey equipment used in this study included a total station theodolite, prisms, and a global positioning system receiver. To characterize the mesohabitats, three transects perpendicular to the channel and about 20 m apart were established across each 50 m reach. There were three measurement points on each transect, located one-fourth, one-half, and three-fourths across the wetted width of the stream channel, starting at the east edge of the flowing water.

To compare changes in channel morphology across time and sites, elevation change was calculated. The first measurements were made 72 days before dam removal. If subsequent measurements indicated an increase in the elevation of the lowest point of a transect, the transect was labeled a deposit area. If elevation of the lowest point decreased, the transect was labeled a scour area. The channel substrate at each of the three points on each transect was classified by the size of the dominant particles (large boulder > 51.2 cm, small boulder 25.6–51.2 cm, rubble 6.4–25.6 cm, pebble 1.6–6.4 cm, gravel 0.2–1.6 cm, and smooth surface < 0.2 cm).

Sampling protocol

We collected six replicates of benthic, aquatic insects with a Surber sampler (area $= 30.48$ cm $\times$ 30.48 cm, mesh size $= 250$ μm) from each of the four sites at each sampling time. We kept the six replicates separately, but defined them as one sampling unit in this study. We selected the actual sampling locations, in runs and riffles, haphazardly, and preserved samples in 75 % ethanol in the field. In the laboratory, elutriation was used to separate organic matter from inorganic matter. We identified nearly all aquatic insects to the genus or species level (Kang 1993; Kawai and Tanida 2005; Merritt et al. 2008), except for the Chironomidae which were classified as Tanypodinae and non-Tanypodinae.

We used binoculars to count the number of dippers at each of the two reaches (upstream and downstream from dam) on six occasions. Each time, two researchers slowly walked upstream for 1,850 m along each reach counting the dippers that were perched or foraging. To avoid recounting, we ignored dippers that flew ahead of us, because territorial individuals characteristically "double-back" when pushed to the ends of their territory.

Data analyses

We characterized each taxon as having or lacking more than one generation per year (Chiu and Kuo 2012). A short life cycle was assumed to lead to shorter generation times and higher population growth. To examine the recovery process after dam removal, we compared the fraction of invertebrates with a short life span among sampling times and among sites.

A nested ANOVA model was used to identify the effects of dam removal on habitat variables (elevation change and substrate size), macroinvertebrate density (log-transformed, $X + 1$), taxa richness, fraction of invertebrates with short life span, and dipper abundance. In the model, Location (upstream and downstream) and Stage (before and after the removal, from May 23 to 30, 2011) are the main factors, and Site and Date are nested factors within Location and Stage, respectively. Possible impacts of dam removal on these biotic and abiotic variables were examined when interactions between Stage and Location were significant (Underwood 1991; Thomson et al. 2005; Orr et al. 2008). Statistical significance for the ANOVA was set at $\alpha = 0.05$.

We examined changes in macroinvertebrate community structure following dam removal. First, we constructed a Bray–Curtis similarity matrix derived from samples, each with a vector having all log $(X + 1)$-transformed, taxon-specific abundance. Based on the matrix, we used ANOSIM (analysis of similarities) to examine whether there were significant differences among three groups: (1) community structure upstream and downstream together before dam removal and (2) community structure upstream and (3) downstream after the removal. In addition, SIMPER (similarity percentage) was used to determine the contribution of each taxon to the dissimilarities among these groups. We summarized the total contribution of taxa having short life span to the dissimilarities. We compared the total contribution between one group (community structure upstream and downstream before the removal) and each of the two groups (community structure upstream or downstream after the removal) to examine the recovery process after the dam removal. The two analyses (ANOSIM and SIMPER) were performed by PRIMER software (Clarke and Warwick 2001). Statistical significance for ANOSIM was set at $\alpha = 0.05$.

Results

After dam removal, a huge elevation gain (0.4–2.8 m) at the downstream sites indicated severe sediment deposition, while moderate scouring or deposition (less than 0.9 m elevation change) was observed at the other sites (Fig. 2). The habitat metric was significantly different between upstream and downstream sites following dam removal (Table 1), and substrate size decreased from 3.3–41.0 to 2.8–21.0 cm at the downstream sites. In contrast, substrate size at upstream sites increased from 1.2–14.2 to 4.5–21.5 cm (Table 1; Fig. 2).

After dam removal, macroinvertebrate densities and taxa richness were significantly different between upstream and downstream sites (Table 1). Before dam removal, consistent, flooding-mediated decreases in macroinvertebrate densities were observed at all sites (Fig. 3; Fig. S1). At downstream sites, post-removal macroinvertebrate densities did not reach pre-removal levels. In contrast, densities at upstream sites increased (Table 1; Fig. 3). Following dam removal, richness decreased at all four sites, but the decrease was greater at downstream than at upstream locations (Table 1; Fig. 3). After dam removal, consistent decreases and subsequent lasting recoveries in short-life span invertebrates were observed at all sites (Table 1; Fig. 3). The effect of "Stage" (before or after dam removal) was marginally insignificant (Table 1; $P = 0.07$). Dam removal did not significantly affect dipper abundance (Table 1).

ANOSIM found significant differences in community structure among the three groups, including (G1) upstream and downstream together before the removal

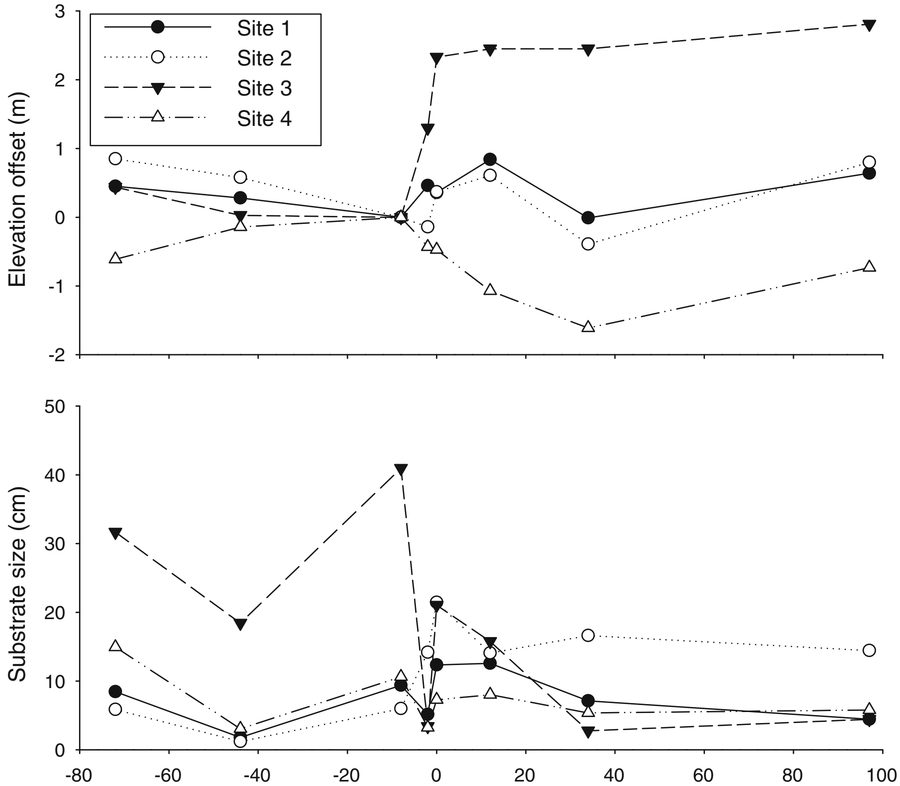

Fig. 2 Changes in elevation offset (from the level on May 23, 2011, the date when dam removal started) and substrate size, upstream and downstream of the dam during the study period. Time is shown as the number of days before and after May 30, 2011, the date when the dam was completely removed

Table 1 Results of nested ANOVA for macroinvertebrate density and richness, fraction of the invertebrates with a short life span, bird abundance, and habitat variables

	Invertebrate density		Invertebrate taxa richness		Short-lived invertebrates		Bird abundance		Elevation change[a]		Substrate size	
	F	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Location	16.50	0.0012	3.25	0.0931	0.04	0.8431	1.64	0.2698	0.01	0.9261	10.18	0.0078
Stage	23.27	0.0003	33.72	<0.0001	2.73	0.1207	5.97	0.0710	5.73	0.0339	3.45	0.0878
Location × Stage	12.50	0.0033	7.04	0.0189	0.15	0.7055	0.66	0.4611	5.92	0.0316	42.15	<0.0001
Site(L)	1.25	0.3153	1.14	0.3490	1.11	0.3570	–	–	32.40	<0.0001	18.19	0.0002
Date(S)	7.39	0.0008	1.30	0.3213	4.07	0.0122	1.37	0.3850	1.62	0.2245	5.26	0.0072
Location × Date(S)	0.79	0.6063	1.12	0.4043	0.78	0.6150	–	–	0.51	0.7902	0.72	0.6386
Stage × Site(L)	1.45	0.2684	3.15	0.0742	3.16	0.0737	–	–	19.72	0.0002	11.59	0.0016

Letters (L or S) in parentheses after a main factor indicate the nested factor within Location (upstream and downstream) or Stage (before and after the removal), respectively. Significant Location × Stage interaction indicates a possible impact of dam removal. In addition, a significant Site(L) value indicates significant difference between Sites within each Location, and a significant Date(S) value indicates a significant difference between Dates within each Stage

[a] The elevation offset from the level on May 23, 2011, the date when dam removal started

and (G2) upstream and (G3) downstream after the removal (G1 vs. G2, $R = 0.310$, $P = 0.001$; G1 vs. G3, $R = 0.452$, $P = 0.001$; G2 vs. G3, $R = 0.256$ $P = 0.001$). Using SIMPER analysis, we found that taxa with short life spans accounted for 33.21 % of the change in community structure along the impact gradient and 29.74 % of the change along the seasonal gradient.

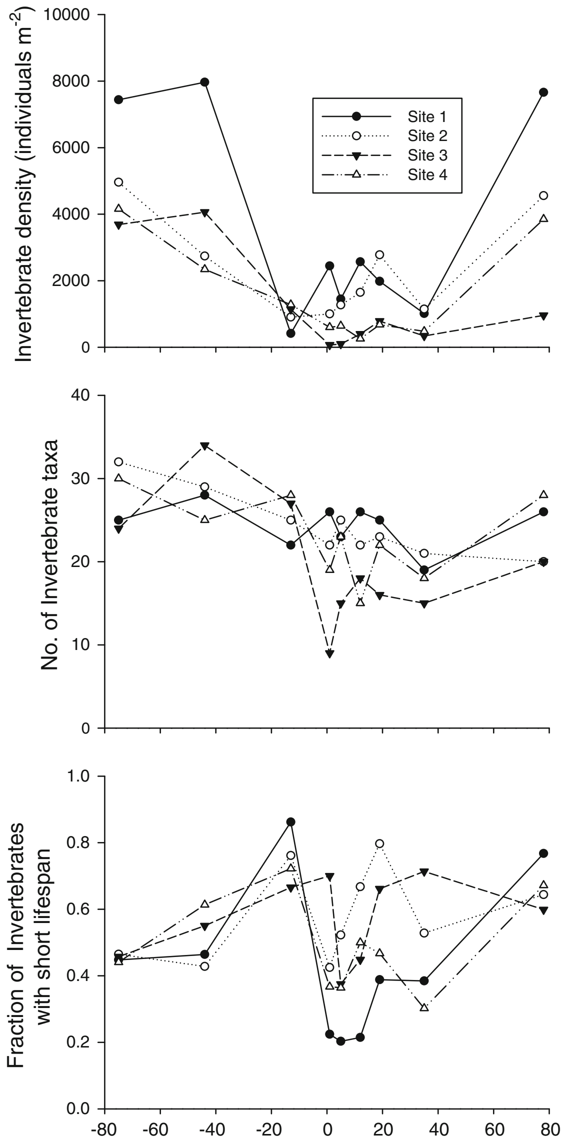

Fig. 3 Changes in macroinvertebrate density, taxa richness, and the fraction with short life span, upstream and downstream of the dam during the study period. Time is shown as the number of days before and after May 30, 2011, the date when the dam was completely removed

Discussion

Removal of the check dam was followed by an immediate decrease in the number of macroinvertebrates at downstream sites. However, macroinvertebrate numbers rebounded during the 4 months we collected data post-removal. The decrease in density was associated with the downstream transport of impoundment sediments. However, Brown Dippers appeared to be unaffected by the decrease in prey densities. In general, dippers did not spend more time sampling locations with higher densities of invertebrate prey. Although macroinvertebrate densities at downstream sites increased in the months following dam removal, they remained low relative to the densities at upstream sites.

Impacts of dam removal on macroinvertebrates

Dam removal led to a dramatic release of the sediments accumulated behind the dam into downstream reaches. This sediment movement was similar to that resulting from other types of natural and anthropogenic disturbances, including flash floods (Robinson et al. 2004) and runoff from agricultural and deforested/clear-cut areas (MacKenzie 2008; Johannsen and Armitage 2010). Movement of large amounts of sediment immediately reduces benthic populations, including algae and invertebrates, through scouring and burial by transient sediment pulses in our and other streams (Orr et al. 2008). Other studies also have found that dam removal can alter invertebrate community composition and reduce macroinvertebrate richness (Bushaw-Newton et al. 2002; Thomson et al. 2005).

The change in the community structure during the recovery period resulted from differential responses among taxa. As a rule, *r*-selected taxa, characterized by small body size, a short life span, and rapid reproduction (Pianka 1970), overcome the impacts of disturbances more quickly than *K*-selected taxa. Sediment reduces the amount of interstitial space and alters substrate composition. As a result, the invertebrate community that arises during the recovery period includes more taxa that are adapted to, or tolerant of, the sediment (Townsend et al. 2008). Spates of sediment deposition result in unstable and transient environments that may filter out larger, longer-lived, *K*-selected taxa (Townsend and Thompson 2007; Larsen et al. 2011). We predicted that a drop in the relative abundance of intolerant, *K*-selected taxa and the rapid recovery of small, *r*-selected taxa explains changes in community composition downstream of the dam following dam removal. In a two-month study, Orr et al. (2008) found that trichopterans and ephemeropterans, which are relatively large and long-lived, were severely affected by dam removal, while short-lived dipterans recovered quickly. In our study invertebrate abundance recovered rapidly, and this was due, almost entirely, to an increase in taxa with small bodies (e.g., chironomid larvae) at both upstream and downstream sites. Prior to dam removal, severe flooding in this watershed caused similar changes in community composition (Chiu and Kuo 2012) and had other impacts on the macroinvertebrate community. As a result, the removal was associated with only minor changes in the downstream community structure of short-lived taxa.

In our study and others, sediment pulses may persist for a few hours to several days after dam removal (Doyle et al. 2003; Orr et al. 2008). In addition, as in our study, post-removal floods can wash sediments from reservoirs, resulting in repeated sediment pulses over several years (Ahearn and Dahlgren 2005). Thus, while macroinvertebrate density can recover relatively quickly downstream of the former dam, it can be reduced again and again by flood-mediated sediment pulses (Thomson et al. 2005). Complete recovery of taxonomic similarity, richness, and density may take several years to decades (Hansen and Hayes 2012) and may not occur until sediment inputs return to pre-removal levels.

Dipper response to dam removal

Macroinvertebrates are an important factor affecting the abundance of Brown Dippers (Chiu et al. 2008) and constitute the majority of items in the diet of dippers in our study area and elsewhere (Buckton and Ormerod 2008; Chiu et al. 2009). When their food supply decreases, dipper populations also decrease (Ormerod et al. 1986; Tyler and Ormerod 1992), but the size of their territories increases (Vickery 1991). However, in our study, dam removal had little effect on dippers. There was a clear decrease in the number of dippers immediately after the dam was removed, but dipper numbers increased somewhat in the following months. Some of these changes may be the result of normal, seasonal fluctuations, such as an increase in territory size and mobility during the nonbreeding season.

Our study documented the short-term effects of dam removal, from days to several months after the removal. However, long-term studies, lasting from years to decades after removal, are needed to assess the effects of dam removal on macroinvertebrates and dippers and develop plans for mitigating impacts.

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References

Ahearn DS, Dahlgren RA (2005) Sediment and nutrient dynamics following a low-head dam removal at Murphy Creek, California. Limnol Oceanogr 50:1752–1762

Buckton ST, Ormerod SJ (2008) Niche segregation of Himalayan river birds. J Field Ornithol 79:176–185

Bushaw-Newton KL, Hart DD, Pizzuto JE, Thomson JR, Egan J, Ashley JT, Johnson TE, Horwitz RJ, Keeley M, Lawrence J, Charles D, Gatenby C, Kreeger DA, Nightengale T, Thomas RL, Velinsky DJ (2002) An integrative approach towards understanding ecological responses to dam removal: the Manatawny Creek Study. J Am Water Resour Assoc 38:1581–1599

Casper AF, Thorp JH, Davies SP, Courtemanch DL (2006) Ecological responses of zoobenthos to dam removal in the Kennebec River, Maine, USA. Arch Hydrobiol Suppl Large Rivers 16:541–555

Catalano MJ, Bozek MA, Pellett TD (2007) Effects of dam removal on fish assemblage structure and spatial distributions in the Baraboo River, Wisconsin. N Am J Fish Manage 27:519–530

Chiu M-C, Kuo M-H (2012) Application of *r/K* selection to macroinvertebrate responses to extreme floods. Ecol Entomol 37:145–154

Chiu M-C, Kuo M-H, Sun Y-H, Hong S-Y, Kuo H-C (2008) Effects of flooding on avian top-predators and their invertebrate prey in a monsoonal Taiwan stream. Freshw Biol 53:1335–1344

Chiu M-C, Kuo M-H, Tzeng C-S, Yang C-H, Chen C–C, Sun Y-H (2009) Prey selection by breeding brown dippers, *Cinclus pallasii*, in a Taiwan mountain stream. Zool Stud 48:761–768

Clarke KR, Warwick RM (2001) Changes in marine communities: an approach to statistical analysis and interpretation, 2nd edn. PRIMER-E, Plymouth

Doyle MW, Stanley EH, Harbor JM (2003) Channel adjustments following two dam removals in Wisconsin. Water Resour Res 39:1011–1025

Feck J, Hall RO (2004) Response of American dippers (*Cinclus mexicanus*) to variation in stream water quality. Freshw Biol 49:1123–1137

Federal Interagency Stream Restoration Working Group (2001) Stream corridor restoration: principles, processes, and practices. National Engineering Handbook; Part 653. Washington, D.C. USA. Accessible at: http://purl.access.gpo.gov/GPO/LPS63051

Hansen JF, Hayes DB (2012) Long-term implications of dam removal for macroinvertebrate communities in Michigan and Wisconsin rivers, United States. River Res Appl 28:1540–1550

Hart DD, Johnson TE, Bushaw-Newton KL, Horwitz RJ, Bednarek AT, Charles DF, Kreeger DA, Velinsky DJ (2002) Dam removal: challenges and opportunities for ecological research and river restoration. Bioscience 52:669–681

Johannsen SS, Armitage P (2010) Agricultural practice and the effects of agricultural land-use on water quality. Freshw Forum 28:45–59

Kang S-C (1993) Ephemeroptera of Taiwan (excluding Baetidae). PhD dissertation, National Chung Hsing University, Taichung, Taiwan

Kawai T, Tanida K (eds) (2005) Aquatic insects of Japan: manual with keys and illustrations. Tokai University Press, Tokyo

Larsen S, Pace G, Ormerod SJ (2011) Experimental effects of sediment deposition on the structure and function of macroinvertebrate assemblages in temperate streams. River Res Appl 27:257–267

Lytle DA, Poff NL (2004) Adaptation to natural flow regimes. Trends Ecol Evol 19:94–100

MacKenzie RA (2008) Impacts of riparian forest removal on Palauan streams. Biotropica 40:666–675

Merritt RW, Cummins KW, Berg MB (2008) An introduction to the aquatic Insects of North America, 4th edn. Kendall/Hunt Publ. Co., Dubuque, IA

Minshall GW, Andrews DA, Manuel-Faler CY (1983) Application of island biogeography theory to streams, macroinvertebrate recolonization of the Teton River, Idaho. In: Barnes JR, Minshall GW (eds) Stream ecology, applications and testing of general ecological theory. Plenum Press, New York, pp 279–297

Ormerod SJ, Allinson N, Hudson D, Tyler SJ (1986) The distribution of breeding dippers [*Cinclus cinclus* (L); Aves] in relation to stream acidity in upland Wales. Freshw Biol 16:501–507

Orr CH, Kroiss SJ, Rogers KL, Stanley EH (2008) Downstream benthic responses to small dam removal in a coldwater stream. River Res Appl 24:804–822

Pianka ER (1970) On *r*- and *K*-selection. Am Nat 104:592–597

Poff NL, Hart DD (2002) How dams vary and why it matters for the emerging science of dam removal. Bioscience 52:659–668

Poff NL, Allan JD, Bain MB, Karr JR, Prestegaard KL, Richter BD, Sparks RE, Stromberg JC (1997) The natural flow regime. Bioscience 47:769–784

Pollard AI, Reed T (2004) Benthic invertebrate assemblage change following dam removal in a Wisconsin stream. Hydrobiologia 513:51–58

Robinson CT, Uehlinger U, Monaghan MT (2004) Stream ecosystem response to multiple experimental floods from a reservoir. River Res Appl 20:359–377

Sethi SA, Selle AR, Doyle MW, Stanley EH, Kitchel HE (2004) Response of unionid mussels to dam removal in Koshkonong Creek, Wisconsin (USA). Hydrobiologia 525:157–165

Skalak K, Pizzuto J, Hart DD (2009) Influence of small dams on downstream channel characteristics in Pennsylvania and Maryland: implications for the long-term geomorphic effects of dam removal. J Am Water Resour Assoc 45:97–109

Stanley EH, Doyle MW (2003) Trading off: the ecological removal effects of dam removal. Front Ecol Environ 1:15–22

Stanley EH, Luebke MA, Doyle MW, Marshall DW (2002) Short-term changes in channel form and macroinvertebrate communities following low-head dam removal. J N Am Benthol Soc 21:172–187

Thomson JR, Hart DD, Charles DF, Nightengale TL, Winter DM (2005) Effects of removal of a small dam on downstream macroinvertebrate and algal assemblages in a Pennsylvania stream. J N Am Benthol Soc 24:192–207

Townsend CR, Thompson RM (2007) Body size in streams: macroinvertebrate community size composition along natural and human-induced environmental gradients. In: Hildrew AG, Raffaelli DG (eds) Body size: the structure and function of aquatic ecosystems. Ronni Edmonds-Brown. Cambridge University Press, Cambridge, pp 77–97

Townsend CR, Uhlmann SS, Matthaei CD (2008) Individual and combined responses of stream ecosystems to multiple stressors. J Appl Ecol 45:1810–1819

Tyler SJ, Ormerod SJ (1992) A review of the likely causal pathways relating the reduced density of breeding dippers *Cinclus cinclus* to the acidification of upland streams. Environ Pollut 78:49–55

Underwood AJ (1991) Beyond BACI: experimental designs for detecting human environmental impacts on temporal variations in natural populations. Aust J Mar Freshw Res 42:569–587

Vickery J (1991) Breeding density of dippers (*Cinclus cinclus*), grey wagtails (*Motacilla cinera*), and common sandpipers (*Actitis hypoleucos*) in relation to the acidity of streams in south-west Scotland. Ibis 133:178–185