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Of sand slugs and fish restoration: the Granite Creeks saga

N.R. Bond and P.S. Lake
School of Biological Sciences and CRC for Freshwater Ecology
Monash University VIC 3800

Nick.Bond@sci.monash.edu.au

Abstract

Land clearance and grazing in the granitic Strathbogie Ranges, combined with disturbances by floods, droughts and bushfires, have caused massive export of sediment into the channels of lowland creeks — the Granite Creeks — creating lengthy sand slugs. Consequently the 'chain of ponds' form of the creeks has been converted into flat, shallow sections with low habitat complexity, reducing fish diversity and abundance. Three fish species — *Galaxias olidus, Gadopsis marmoratus* and *Nannoperca australis* — were targeted for possible restoration. Prior to selecting the form of restoration, we identified factors strongly associated with the habitats of the fish. Subsequently, timber structures, which were designed to create scour pools, were made from river red gum sleepers and installed in May 2001 in Creightons and Castle Creeks. Prior to restoration, fish abundance and diversity were assessed at all of the experimental sites. In each creek, there were 3 control sites, 3 sites with one structure, and 3 sites with four structures. There was a relatively rapid response by the fish to the structures, this response being particularly strong for *G. olidus.* However, in late 2001 and 2002 the effects of a lengthy drought became evident with a loss of water in the sand-slugged channels. Fish abundance was greatly reduced though the reduction was partly ameliorated by the structures and attendant scour pools.

While fish populations responded positively to the habitat restoration in the short term at a local scale, a large-scale and long-duration disturbance — drought — overrode this response. This illustrates the need not only to restore residential habitats predictably used in the life histories of the fish, but also to restore habitats that are refugia in unpredictable disturbances.

Introduction

The degradation of streams and rivers following European settlement of southeastern Australia has been widespread, with much of this degradation attributable to the erosion and consequent sedimentation that followed extensive land clearing. In many catchments, particularly those composed of coarser sediments (for example granitic sands), erosion delivered sediments incapable of being transported long distances in suspension, resulting in the deposition of large volumes of material within the stream channel itself. This in turn resulted in large static bodies of sediment, commonly referred to as sand slugs (Nicholas *et al.* 1985). Sand slugs effectively inundate the natural bedform and in-stream structural elements such as large timber, resulting in a flat, shallow and homogeneous bed. The decrease in channel volume increases the frequency of overbank flows, and dry spells with no surface water may occur when water levels drop below the sand surface. These physical and hydrologic changes have a marked impact on stream biota causing declines in abundance and diversity. Sand slugs have developed in many catchments in southeastern Australia (see Bartley & Rutherfurd 2001), and there is now considerable interest in trying to restore sand slug-affected streams and rivers.

Degradation of the Granite Creeks system

Our work has been carried out in the so-called 'Granite Creeks' (Castle, Creightons and Pranjip Creeks), which drain in a northwesterly direction from the Strathbogie Ranges, a granite massif located in central Victoria. Catchments of the Strathbogie Ranges were first settled by squatters in the 1850s, with land clearing beginning shortly thereafter, and continuing through until the 1950s (Davis & Finlayson 2000). Today less than 30% of the natural vegetation communities within these catchments remains intact (Anonymous, 1999). Erosion of the catchments was first noticed in the late 1800s, but occurred predominantly during the 1900s, as a series of distinct sporadic episodes following heavy rains and floods (1916, 1952–1956, 1993–1994), drought (1982–1983) and bushfires (1990–1991) (Davis & Finlayson 2000). During these events, sediment was rapidly transported from gullies in the headwaters onto the 'flats' – sections of stream crossing the Goulburn River floodplain – where, with very low stream power, extensive sand slugs 20–30 km in length and 1–3 m deep were created (Davis & Finlayson 2000; Bartley & Rutherfurd 2001).

Sand slugs converted these creeks from 'chain of pond' systems (*sensu* Eyles 1977) with deep interconnected slow-flowing pools with high loadings of fallen timber, into shallow, homogeneous fast flowing streams. Permanent pools that previously acted as summer low-flow refuges have also been lost, and the fish assemblage is now considerably degraded. Anecdotal recollections and newspaper reports make it clear that large catches of Macquarie perch and river blackfish from pools in Castle and Creightons Creek were common in the early part of the 1900s, with Murray [or trout?] cod also caught on occasion. There were also regular catches of introduced species (trout, redfin perch and possibly some carp) in the mid 1900s. There was only scant reference to the smaller natives [minnows *sic*], in these early reports, but today it is only the smaller bodied species of fish that remain (Bond & Lake 2003a). Species of fish that have persisted include river blackfish (*Gadopsis marmoratus*), mountain galaxias (*Galaxias olidus*), southern pygmy perch (*Nannoperca australis*) and western carp gudgeons (*Hypseleotris klunzingeri*), but each of these is now only present in low numbers within the sanded creeks (Bond & Lake 2003a).

Restoration

The degree and spatial extent of geomorphic change caused by the sand slugs essentially rules out any chance of restoring these creeks to their natural geomorphic configuration. However, because the sand slugs are now virtually static (Davis & Finlayson 2000), and hence likely to persist for hundreds to thousands of years (Bartley & Rutherfurd 2001), active intervention provides the only real prospect for restoring the biota in sand slugged streams, albeit at a fairly limited scale. It is worth noting that in some larger rivers dredging of sand has been deemed an appropriate intervention; however, the unsorted sands in the granite creeks are of limited value, access is typically difficult, and this sort of intervention is unlikely to restore ecological values (e.g. see Lintermans 2001), and may create additional erosion and siltation problems (Rutherfurd & Budahazy 1996).

We conducted a habitat manipulation trial in which large timber structures were introduced at individual sites in an attempt to increase local habitat complexity, with the expectation that this would engender a positive biotic response in terms of the diversity and abundance of fish and invertebrates (the field of dreams hypothesis; Palmer *et al*. 1997). This strategy, and the anticipated outcomes were based on the knowledge that (1) large timber plays a key role in maintaining geomorphic complexity in lowland streams via processes of localised sediment scour and fill, and (2) patterns of abundance and diversity in fish and invertebrates are correlated with the distribution of large timber, both in the Granite Creeks system (O'Connor 1992; Bond & Lake 2003a; Downes *et al.* in press) as well as more generally (Crook & Robertson 1999; Lemly & Hilderbrand 2000).

The setting of clear targets is an integral and necessary component of restoration activities. By treating targets as predictions, whether from conceptual, simulation or statistical models, they can be framed as hypotheses that act as critical tests of our understanding of the system, as well as allowing project performance to be measured. The process of developing targets provides an opportunity to explicitly consider what might be achievable and / or desirable outcomes; also, targets that are agreed to and accepted by all stakeholders can prevent later disputes about the success or failure of a project.

In this case we had collaborative assistance from the local stream management agency (the Goulburn-Broken Catchment Management Authority; GBCMA) as well as strong support from local Landcare groups and the wider community.

Ideally targets are set based on data from unimpacted 'reference' sites (Downes *et al.* 2002), but such sites are virtually absent from streams on the Goulburn floodplain due to the overarching impacts associated with broad-scale agriculture (see Bond & Lake 2003a; Downes *et al.* in press). However, in previous surveys within the sanded stream sections, galaxiids, blackfish and southern pygmy perch all showed associations with deeper water and small-scale habitat structure, thus lending support to adding in-stream structures as a potential strategy for biotic restoration (Bond & Lake 2003a). Taking into account the impossibility of restoring the streams across the entire length of the sand slug, and hence the realities of likely dispersal bottlenecks (see Bond & Lake 2003b), we restricted our targets for fish to increases in the abundances of those smaller bodied species still present within the sanded sections, rather than the complete historical fish community.

Experimental design

The experiment consisted of a single treatment — the addition of large timber structures — with three levels (control, 1-structure/site and 4-structures/ site) applied to sites that consisted of 100 m of stream largely free of large timber. At several sites there were riparian trees with undercut root masses that provided some initial habitat for fish, but variations between sites were factored out by replication and random assignment of treatments as part of the experimental design. Each treatment was replicated 3 times in each of two creeks: Castle Creek and Creightons Creek. The structures were put in place in May 2001 in collaboration with the GBCMA, and samples were collected 3 times before (Nov 2000, Jan 2001, Mar 2001) and 4 times after (Sep 2001, Nov 2001, May 2002 and Aug 2002) the placement of the structures. Structures consisted of multiple red gum sleepers bolted together to span the channel perpendicular to the flow (see Bond & Lake 2003a for full details). Surveys consisted of two passes with a backpack electrofisher, and on each occasion all fish collected were counted, measured and returned to the stream.

Data analysis

The data were analysed using a Poisson Bayesian model, the Poisson distribution being well suited to count data (especially of fish!). Bayesian modelling employs Bayes' Theorem to provide an updated (posterior) estimate of a parameter based on previous (prior) information or beliefs together with the data at hand. In this case the parameters we attempted to estimate were the average abundances of fish in each treatment before and after the addition of timber, and hence differences in each treatment over time. Differences in the change over time (i.e. 'average after abundance' minus 'average before abundance') between treatments represent treatment effects, just as in a traditional BACI (before–after control–impact) design. We adopted very vague estimates (i.e. high variances) for the 'prior' parameter estimates, and centred the likely treatment effects for each treatment to zero (i.e. no effect). In this way the posteriors are conservative and can be reliably expected to reflect the effects observed in the experiment, rather than being influenced by prior 'beliefs', thus overcoming one of the common criticisms of Bayesian methods. The model and the analysis routine (conducted using the WINBUGS package; Spiegelhalter *et al.* 2003) are beyond the scope of this paper, and readers are encouraged to refer to Bond and Lake (2004) for more details.

Results and discussion

Here we present a summary of the results; readers are again referred to Bond and Lake (2004) for more details. In the short term, despite some species undergoing widespread declines in abundance (i.e. across all sites and treatments), there was a generally positive response to the timber additions, although these changes were greatest in response to the 4-structure treatment (**Table 1, Figure 1**). In some cases these changes were strongly positive. In particular, in response to the 4-structure treatment, mountain galaxiids underwent an almost 3-fold increase in abundance in Creightons Creek and doubled in abundance in Castle Creek (**Table 1**).

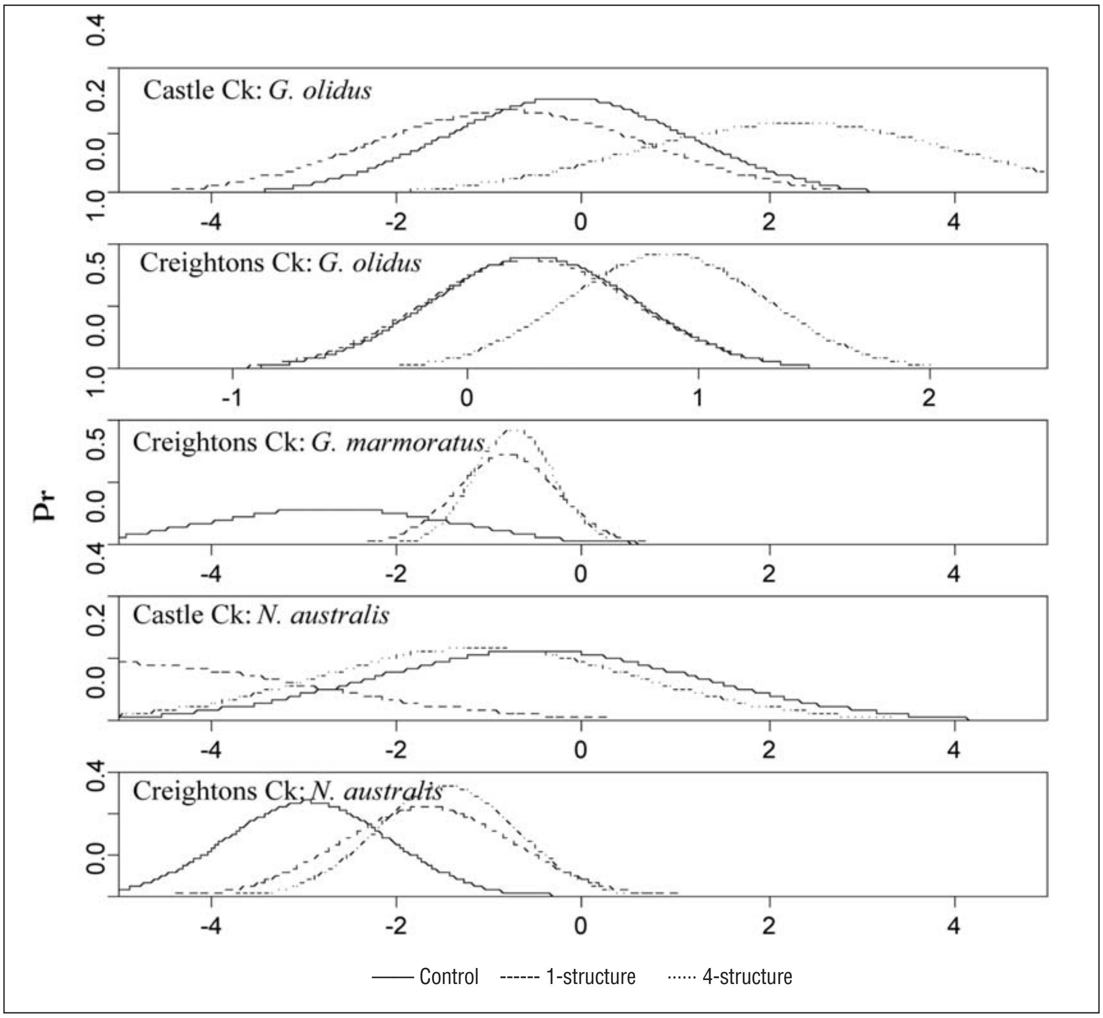
Table 1. Mean (± SE) abundances of common taxa in each treatment before and after, and treatment effects after, the timber structures were put in place. SE calculated by pooling across replicate sites and times.

Species and site	treatment	before	after	difference
G. olidus				
Castle Ck	0	37.0 ± 0.4	24.3 ± 20.2	–12.7 ± 20.2
	1	52.0 ± 22.8	20.3 ± 16.0	–31.7 ± 27.9
	4	13.4 ± 13.4	28.2 ± 17.0	+14.8 ± 21.6
Creightons Ck	0	9.6 ± 1.9	13.4 ± 6.1	+ 3.8 ± 6.4
	1	15.0 ± 3.5	20.3 ± 8.4	+ 5.3 ± 20.7
	4	15.3 ± 4.1	35.4 ± 9.9	+20.1 ± 10.7
G. marmoratus				
Castle Ck	0	—	—	—
	1	—	—	—
	4	—	—	—
Creightons Ck	0	1.0 ± 0.3	0.1 ± 0.1	–0.8 ± 0.3
	1	2.1 ± 0.4	1.0 ± 0.2	–1.1 ± 0.6
	4	4.6 ± 1.6	2.3 ± 1.4	–2.3 ± 2.1
N. australis				
Castle Ck	0	0.9 ± 0.7	0.3 ± 0.3	–0.7 ± 0.8
	1	3.3 ± 1.0	0.1 ± 0.1	–3.2 ± 1.0
	4	2.0 ± 1.7	0.7 ± 0.7	–1.3 ± 1.8
Creightons Ck	0	25.8 ± 9.5	3.0 ± 2.2	–22.8 ± 9.8
	1	13.3 ± 0.5	2.6 ± 0.2	–10.7 ± 0.5
	4	16.9 ± 6.4	5.4 ± 4.3	–11.5 ± 7.7

At the same time, populations at both the control and the 1-structure treatment sites remained similar in Creightons Creek, and declined in Castle Creek (controls declined furthest), indicating a strong effect associated with the 4-structure treatment. Blackfish populations in Creightons Creek (this species is absent from Castle Ck) declined overall, but these declines were buffered by the structures, with populations at the 4-structure sites (despite strong declines) performing better than the 1-structure and control sites respectively. Pygmy perch showed no real response, with declines in abundance at sites in both Creightons and Castle Creeks. Despite high variances between individual sites, the Poisson model provided a generally good fit to the data, and the analysis provided strong evidence that the treatments did differ, with divergences between the posterior distributions for the three treatments (**Figure 1**). Although there was clearly recruitment at some sites, we stress that much of the observed response could be attributable to aggregation of fish at the manipulated sites, rather than changes in the total population size.

Subsequent to the emergence of a positive treatment effect, however, an extended drought affected the creeks. In the summer of 2002–2003, both Castle and Creightons Creeks dried out throughout the sand slug, resulting in extensive mortality of fish, a fate that was greatly exacerbated by the absence, within the sand slug, of permanent refuge pools in which fish might otherwise have persisted. Subsequent to this, fish populations have again been subjected to drying over the 2003–2004 summer, and despite colonisation by a small number of individuals in the 2003 winter (especially galaxiids), the populations have declined dramatically relative to the pre-drought levels (Bond, unpublished data). Thus, overall, despite initial positive increases in fish abundances in response to the addition of physical habitat – a response that we feel is indicative of the likely benefits of habitat restoration in perennial streams – the drought caused declines in fish abundances to low levels from which populations will undoubtedly be slow to recover.

Figure 1. Modelled (log_e(△ abundance)) posterior distributions for changes in fish abundances in each creek after the sleeper additions. Note in particular the stronger shift away from zero for the 4-structure treatment for Galaxias olidus, *and (variable) declines in* Gadopsis marmoratus *at the control sites.*



Droughts are an integral component of the Australian climate, and one to which the biota are generally adapted. To persist through droughts, many taxa in lowland systems have historically relied on refuge habitats provided by permanent (sometimes spring-fed) pools (Lake 2003). In the Granite Creeks system these habitats are amongst those to have been destroyed by sand slugs, but they were not targeted by our restoration efforts. Some refuge pools did persist through the drought, above and below the sand slug, and these harboured large numbers of fish. Surveys to determine the longer-term trajectory of these populations, hopefully beyond the drought period, are ongoing. Hypothetically, the presence of refugia throughout the sand slug would have greatly increased the number of fish that survived, and also provided important sites from which recolonisation could occur. This would greatly accelerate the recovery time from drought events, an outcome that may become increasingly relevant if drought events become more common, as has been suggested with predicted climatic changes across the Murray-Darling Basin (Kershaw *et al*. 2003; Pittock 2003). While we lack specific data to demonstrate the importance of refugia, the inclusion of drought refugia in restoration planning for lowland rivers likely to undergo intermittent drying could be just as important as restoring the residential habitats that are normally targeted in restoration — a point we have made elsewhere (Bond & Lake 2005).

Similar arguments could be made for other habitats that are only intermittently important, or are used only at particular times through the life history of particular species (Fausch *et al.* 2002; Roni *et al.* 2002). Thus far, most fish habitat restoration work in Australia has focused on adult residential habitats, despite obvious specific needs at other times during the lifecycle (e.g. spawning and larval habitats; Bond & Lake 2003b).

Conclusions

To summarise our current findings, the introduction of large timber to sand-slugged streams locally increased fish abundances, but only under conditions of sufficient flow. The restoration work we carried out targeted residential habitat, which did little to enhance the drought resistance of the fauna. The creation / restoration of specific refuge habitats will be a challenging task in sanded streams because the mobility of the bed material means that large pools are generally rapidly infilled (Lintermans 2001). One solution may be to rely on scour around structures during high flows as we did in this study, but to design the structures in a way that isolates the downstream pool from upstream sediment supply during low-flow periods (Dan Borg, University of Melbourne, pers. comm.). Such strategies will require development and testing via collaborations between hydrologists, geomorphologists and ecologists. Stream managers also should not rule out the potential need for ongoing intervention to protect critical refuge habitats that may serve important roles in both conservation and restoration.

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