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# Patch-specific spawning is linked to restoration of a sediment-disturbed lowland river, south-eastern Australia

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ABSTRACT

Landscape-scale, terrestrial modifications of catchments can increase river sediment loads. In some rivers, the development of 'sand-slugs' (i.e. discrete slugs of travelling sand particles) subsequently alters habitat structure with links to declines in regional fish diversity. Increasingly, river channel restoration is being used to conserve biodiversity in sediment-disturbed rivers, but there are few examples to guide restoration efforts. In particular, few studies examine the effect of restoration on ecological processes such as spawning. We report on a trial restoration procedure, consisting of sediment extraction and woody debris replacement undertaken in two 1500 m reaches of the Glenelg River, south-eastern Australia. We aimed to examine the association between reach-scale restoration and fish spawning, predicting that reconstructed channel types (pools and runs) would be used more frequently than corresponding un-modified channel types for spawning. Artificial (polyvinylchloride (PVC) tubes) and natural (small woody debris) spawning substrates were used to examine the association of fish spawning with reach and channel type. Restoration increased wood volume, but only increased average run depth at one reach. Species including *Gadopsis marmoratus*, *Philypnodon grandiceps*, *Hypseleotris* spp., *Nannoperca variegata* and *Cherax destructor* were observed within spawning substrates, but only *P. grandiceps* frequently spawned on PVC tubes and sparsely on small woody debris substrates. Spawning frequency varied between reach and channel types, with pools in both restored and un-manipulated reaches used more frequently than runs. Restored pools were less frequently used than un-manipulated pools, but restored runs were used up to 6 times more frequently than un-manipulated runs, indicating that restoration of the shallowest parts of the channel increased spawning opportunities for *P. grandiceps*. This type of channel restoration may facilitate ecological processes that underpin the persistence of riverine fish populations.



## 1. Introduction

Terrestrial modification of catchment landscapes around the world and the subsequent, inflated export of sediment to river channels results in the development of slow-moving, discrete slugs of sand-size particles known as 'sand-slugs' (Lind et al., 2009). Sand-slugs are most apparent in low-gradient or lowland reaches where their physical impact is clear—burial of habitat-patches (e.g. pools) and components (e.g. woody debris) maintaining habitat-patches, by up to several meters of sediment. These changes to channel structure can influence habitat function and the roles of habitat-patches for biota (Bond and Lake, 2005), especially in streams flowing across Mediterranean or semi-arid landscapes where water is scarce and abstraction or diversion common. Low summer water levels mean that shallow channels with sand-slugs are exposed to further disturbance, including increased risk of desiccation (O'Connor and Lake, 1994; Bond and Lake, 2005) and higher summer stream temperatures (Alexander and Hansen, 1986).

Declines in biodiversity, notably the absence of species from fish assemblages, has corresponded with significant deposits of sediment and subsequent changes to habitat structure (Berkman and Rabeni, 1987; Waters, 1995). Sediment transport and the burial of substrates by sand and silt-size particles, are widely reported to be detrimental to benthic specialists (Cordone and Kelly, 1961; Ryan, 1991; O'Connor and Lake, 1994; Wood and Armitage, 1997; O'Connor and Zampatti, 2006). This is especially true for families with life-history traits that increase their vulnerability to sediment deposition such as the use of benthic substrates for oviposition or embryonic development (Cordone and Kelly, 1961; Berkman and Rabeni, 1987; Ryan, 1991; Jones et al., 1999; Burkhead and Jelks, 2001; Sutherland et al., 2002; Walters et al., 2003; Gillenwater et al., 2006; O'Connor and Zampatti, 2006). Fish reproductive pro-

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cesses, in particular, are closely tied to the physical environment (Matthews, 1998) and sensitive to sustained changes to habitat structure, such as those arising from press-type disturbances (e.g. altered flow, thermal or sediment regimes) (Regetz, 2003; Aarts et al., 2004; Gillenwater et al., 2006). Habitat resources used for key reproductive purposes such as oviposition, including channel patches (e.g. pool or riffle) or components (e.g. large woody debris, gravel, depth, undercut banks) correspond to the distribution and number of spawning events (Magee et al., 1996; Knapp et al., 1998; Dauble and Geist, 2000; Merz, 2001). The susceptibility of these resources to burial could mean that spawning is affected in reaches with sand-slugs. For example, Gamradt and Kats (1997) reported that the burial of rock substrates and channel patches (pools and runs) by sediment after recent wildfire disturbance, did not influence abundances of a newt, but the use of channel patches for oviposition decreased by up to 66%. The use of reaches affected by sand-slugs for spawning remains unclear, but the presence of new recruits (age 0+ juveniles) signifies some successful reproduction or at least that the dispersal of juveniles occurs there (Bond and Lake, 2005).

Channel restoration offers a practical solution to sand-slugs in rivers by redistributing lost resources to recreate functional habitat-patches for biota (e.g. disturbance refuge, Bond and Lake, 2005), but matching effective restoration programs with the impacts of multiple anthropogenic disturbances, over different spatial and temporal scales, is challenging (Lewis et al., 1996; George and Zack, 2001). Also, the application of restoration techniques developed in other ecosystems may be inappropriate ('the cookbook myth', see Hilderbrand et al., 2005) when restoration is intended for specific purposes, such as to improve local spawning potential. Therefore, restoration methods currently applied to rivers affected by sand-slugs require evaluation, in order to establish whether the use of particular techniques produces the desired outcome.

Restoration techniques that could be beneficial to fishes inhabiting reaches with sand-slugs such as the replacement of large woody debris pieces have effectively recreated channel structure, including scour pools (Larson et al., 2001; Shields et al., 2004, 2006). Woody debris provides potential spawning benefits because it is used as a substrate to assist embryonic incubation (Jackson, 1978; Nash et al., 1999; Storey et al., 2006) and provides cover while nesting, mate finding or waiting for conditions to promote spawning (Bjornn and Reiser, 1991; Merz, 2001; Wills et al., 2004). The production of scour pools, however, depends on the interaction of woody debris with strong currents so in systems with more variable hydrology (Puckridge et al., 1998) these natural processes could take some time (see Bond and Lake, 2005). Alternatively, other techniques like sediment extraction can 'instantly' create deeper water, while excavated 'sediment traps' placed above restored reaches can manage the on-going downstream sediment movement (Alexander and Hansen, 1983; Avery, 1996). The successful use of sediment extraction to derive ecological benefits over larger reach scales (thousands of meters) is uncertain, as the employment of sediment extraction for in-stream mining purposes is considered damaging to aquatic biota (Harvey and Lisle, 1998; Meador and Layher, 1998).

Although habitat components or resources associated with fish reproduction have been identified, little is known about the association of spawning fish with variation in channel patches (i.e. 'channel type') or the use of modified channel for reproduction in rivers affected by sand-slugs. This information is needed, not only to guide current attempts at restoring reaches with sand-slugs, but also to increase understanding of the wider implications of extended sediment deposition on fish populations (Waters, 1995). Therefore, the aim of this study was to investigate if spawning use, defined as the number of spawning events detected, varied spatially according to channel and reach (restored or un-manipulated) types. If sedimentation affects the use of channel types (pool or run) for spawning, and restoration is beneficial, then spawning use should be positively associated with restored channel. We also hypothesized that replaced woody debris would be used for oviposition, with spawning use linked to the size, complexity and the placing of pieces among channel types.

## 2. Materials and methods

### 2.1. Study sites

The Glenelg River catchment is located in far Western Victoria, Australia (37°30′S, 143°30′E, Fig. 1), covering an area of 12,700 km$^2$. Two thirds of the catchment vegetation is cleared, with stock grazing and broad acre cropping dominating the land-use (Department of Water Resources, 1989). Land clearing has been implicated with severe erosion and sedimentation of tributaries and main-stem reaches (Erskine, 1994; Lind, 2004) with an estimated 10,000–50,000 m$^3$ of sand-size particles stored per kilometer of channel (Lind, 2004). Sediment has transformed channel morphology; runs dominate most reaches, varying between 5 and 20 m in width, 10's and 100's of meters long and usually between 0.3 and 1.2 m deep. Deep pools (up to 8 m) have been in-filled along with the partial or complete burial other important habitat components (e.g. woody debris, undercut banks, T. Howson personal observation). Remaining pools provide some refuge for flora and fauna, but some are affected by saline groundwater intrusion and contain high water conductivities (10,000 $\mu$S cm$^{-1}$) in bottom waters (Lind, 2004; Turner and Erskine, 2005). Sediment and salinity issues are compounded further by water extraction and diversion in the upper catchment, though an environmental flow allocated to the river below Rocklands Reservoir during drier months (October to May) is provided (Lind et al., 2006; Coates and Mondon, 2009).

Fourteen fish species are common to pools and runs in the mid to upper catchment (Howson et al., 2009) with seven species spawning over spring and summer periods (October to February). River blackfish (*Gadopsis marmoratus* Richardson, northern form), flathead gudgeon (*Philypnodon grandiceps* Krefft) and carp gudgeon (*Hypseleotris* spp.) may be used to assess reproductive responses to environmental changes because they are benthic, use wood during spawning (Jackson, 1978; Merrick and Schmida, 1984), eggs and larvae are distinguishable (Koehn and O'Connor, 1990) and may adopt parental care behaviours during embryo incubation (males of *G. marmoratus* and *P. grandiceps* guard eggs).

### 2.2. Rehabilitation procedure

Two reach-scale rehabilitation procedures were completed in different areas of the Glenelg River, one near the town of Harrow (ca. 50 km downstream of Rocklands Reservoir) during February 2003 (described in Howson et al., 2009), the other near the town of Casterton (ca. 60 km downstream of Harrow) in 2004 (Fig. 1). Each rehabilitated reach consisted of an ca. 1500 m length of river, re-modelled using sediment extraction to lower bed height in runs, create and enlarge pools and construct sediment trap hole above the rehabilitated reach to stop sediment further migrating downstream into newly modified reaches (Fig. 2). Large pieces of woody debris (LWD > 0.1 m in diameter) were also inserted (secured with hardwood piles) into each restored reach, but in different con-