MEASURING THE EFFECT OF RIVER REHABILITATION FOR FISHES: LOGISTICAL CONSTRAINTS ON EXPERIMENTAL DESIGN

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Abstract

Studies of the efficacy of rehabilitation efforts are rarely planned to satisfy concerns about experimental design and statistical examination of field data. The study described in this paper is part of the broader Upper Hunter River Rehabilitation Initiative (UHRRI), and is funded by the Australian Research Council, NSW Department of Primary Industries, and Griffith University. The paper examines the process of making real-world decisions to take advantage of the experimental opportunities offered by the UHRRI project in the context of several constraints. A ten-kilometre stretch of the Hunter River has been chosen for rehabilitation, including the addition of Structural Woody Habitat (SWH). Due to funding limits and logistical issues such as property ownership and riverbank access, the fish rehabilitation project has encountered several design constraints. This project will utilize a 'multiple lines of evidence approach' to strengthen the test of the effectiveness of adding artificial SWH to a river system for fishes. This approach will combine conceptual models and predictions describing the expected responses of each fish species to the SWH in riffles and pools, the collection of quantitative data on fish assemblages and the analysis of the movements of fishes. The aims of the study are to investigate: fish distributions prior to and after introduction of human-made SWH into riffles and pools, the composition of fish assemblages associated with SWH in pools, and the movement patterns of fishes utilising SWH. The UHRRI fish project aims to provide crucial information on issues of experimental design, field techniques and fishes response to SWH to help guide practical river rehabilitation efforts, and at the same time, demonstrate sound scientific practice.

Keywords

river rehabilitation, structural woody habitat (SWH), experimental design, spatial confounding, spatial auto-correlation, multiple lines of evidence.

Introduction

There is a vast literature on the influence of Large Woody Debris (LWD) in rivers as a control on channel morphology and as habitat for fishes and other aquatic organisms (see Gregory 2003 for a recent review). As proposed by Gehrke & Brooks (2003) this study will adopt the term Structural Woody Habitat (SWH) rather than LWD, in an attempt to remove the negative connotations often associated with wood in rivers as 'debris' or 'waste material', rather than a critical component of riverine ecosystems. Accumulations of SWH are typically a dominant habitat feature in undisturbed streams in forested landscapes (Lake 1995). Past and continuing human activities have resulted in reduced input and abundance of SWH in Australian rivers due to clearing of riparian vegetation and direct removal for flood mitigation and navigation (Gippel *et al.* 1992). In recent years, rehabilitation programs have been attempted to mitigate negative human impacts on rivers and improve fish habitat, particularly in small streams (Newbury and Gaboury, 1993, White 1996). Practical guidance on rehabilitation is lacking, particularly for the management of wood in large rivers. Most work on wood re-introduction has been done in North America (e.g. Koning *et al*. 1998, Bisson *et al*. 2003). In the last decade, research on the importance of in-stream structure and its rehabilitation has increased in Europe, Japan, South America, Australia and Africa (see Zalewski *et al*. 2003, for review), but again there is still a lack of quantitative research on large rivers and the large-scale effects of rehabilitation. Sampling large river systems is extremely challenging due to their scale, absence of replication and replicate systems and also the usual presence of diffuse confounding influences (Zalewski *et al*. 2003). Similarly, re-introducing wood to large rivers is more challenging than small streams from both a logistical and engineering perspective. Recently, several studies have suggested that fish respond to different levels of complexity in wood structures (Sheilds *et al*. 1994, Monzyk *et al.* 1997). In-stream wood also affects the distribution and abundance of riverine fish by forming meso-habitat (e.g. scour pools, riffles and runs) (Nakamura & Swanson 1993), and various micro-habitats (Crook & Robertson 1999). Crook and Robertson (1999) have suggested three generic ways in which fish in low energy, turbid, lowland rivers of Australia may utilize wood, namely as protection from predators, for foraging, and as landmarks. It is likely that SWH is also used as a spawning substrate, especially for *Gobiomorphus* species (Cadwallader & Backhouse, 1983), and in higher energy rivers such as the Hunter River it is also likely that fish utilise wood as an hydraulic refuge. Brooks *et al*. (2004) noted an increase in fish abundance after the introduction of wood, however, as outlined by Brooks & Cohen (this volume), constraints on the experimental design of that project, do not allow the drawing of conclusions regarding individual species and the potential longer-term population effects of the SWH treatment.

This paper describes the practical experimental design constraints we confronted in the Upper Hunter River Rehabilitation Initiative (UHRRI), a large river rehabilitation project including the design of the fish component of the project and our approach to the design of an effective monitoring strategy to evaluate the responses of fish populations and assemblages to introduced SWH. This part of the UHRRI project will investigate fish distributions prior to and after introduction of human-made SWH into riffles and pools, the composition of fish assemblages associated with SWH at two levels of complexity in pools and how fish utilize SWH (e.g. foraging, hydraulic refuge).

Study area

The Upper Hunter River Rehabilitation Initiative (UHRRI) is a multi-disciplinary river rehabilitation project. The overall aim of the project is to rehabilitate a ten-kilometre reach of the upper Hunter River near the township of Muswellbrook on the central New South Wales coast. The River Style of the reach is classed as a meandering gravel bed stream (Spencer *et al*. 2004). For site selection and description refer to Brierley *et al.* (this volume).

Design Constraints

Diffuse confounding influences could potentially mask the benefits of introducing SWH. The confounding influences identified adjacent to and including the UHRRI reach include: wide scale land clearing, intensive land use, poor riparian condition, regulated flow, fish movement barriers, exotic species, translocated native species, point source saline and sewerage outfalls.

Table 1. Confounding issues and logistical constraints of monitoring design and logistical constraints.

	Issues	Implications	Approach
Spatial Issues	Close proximity of comparative riffles and pools in the UHRRI reach	Anticipated non-independence. Spatial confounding and spatial autocorrelation	Multiple lines of evidence, use of external riffles and pools for comparison with internal riffles and pools
	Close proximity of pool structures to each other	Anticipated non-independence. Spatial confounding and spatial autocorrelation	Intensified sampling post wood introduction, external tagging of individuals
Temporal Issues	Rate of colonisation in/around SWH	Non-independence of SWH units i.e. fish preferences within home ranges	Intensified sampling post SWH introduction, external tagging of individuals
Logistical Constraints	River bank access for large construction machinery	Reduced ability to randomise SWH location	Gain some measure of fish movement between SWH replicates
	Rehabilitation confined to one reach	Constrained choice of treatment/control replicates	Gain some measure of fish movement between pool/riffle replicates
	Unique river style and diffuse confounding factors	Lack of replicable sites for controls within the catchment	Multiple lines of evidence to strengthen case
	Timescale for monitoring is dictated by PhD scholarship, i.e. 18 months post SWH introduction	Long-term trends may not be apparent	Fish monitoring ongoing post PhD study
	Funding	Range of possible techniques constrained. Limited funding for construction of SWH	Utilise available equipment and take full advantage of industry partners

In addition several logistical constraints have been placed on the fish monitoring project by the physical limitations of the overall UHRRI (Table 1). Rehabilitation will be focussed on the ten-kilometre UHRRI reach constraining the number of available sites for experimental manipulations. There will inevitably be some measure of spatial autocorrelation and thus spatial confounding between sites.

Due to the unique geomorphological nature of the rehabilitation reach in relation to nearby reaches (Spencer *et al*. 2004), there is only a limited distance of river in which comparable external controls can be found. To find replicates of a similar nature in the study reach, the riffles selected for introduction of experimental units are relatively close together (i.e. from 160 to 780 metres apart; mean of 307 ± 208 [SD] metres), which may mean a lack of independence of controls and treatments. At this level of spacing it is not only possible, but also highly likely, that fish will move between replicate SWH, meaning that each structure may not provide an independent estimate of effect. The timescale for testing the effectiveness of introducing SWH to a river is largely constrained by the 3 year PhD time frame, although fish population monitoring will continue beyond the PhD but at a much lower frequency. Fish may choose to avoid SWH if sampling frequency and effort is excessive, therefore the frequency of assessing the rate of colonisation around SWH will have to be constrained. Finally, in pools, access for large construction machinery to the river has been an over-riding factor in the location of each SWH unit. Sites were limited by crane access for placement of introduced SWH.

Temporal Design

The fish population will follow a BACI design. Quarterly monitoring of fish populations was conducted for nine months prior to wood introduction into the pools and the riffles. The program will continue for eighteen months following the SWH introduction. Intensified sampling after SWH introduction will be done monthly to gain a measure of colonisation and of the independence of structures. Literature reviews of seasonal trends in fish movement and biology will be incorporated into the conceptual models and *a priori* statements.

Spatial Design

The following spatial design has been developed within the context of the constraints discussed above (Figure 1).

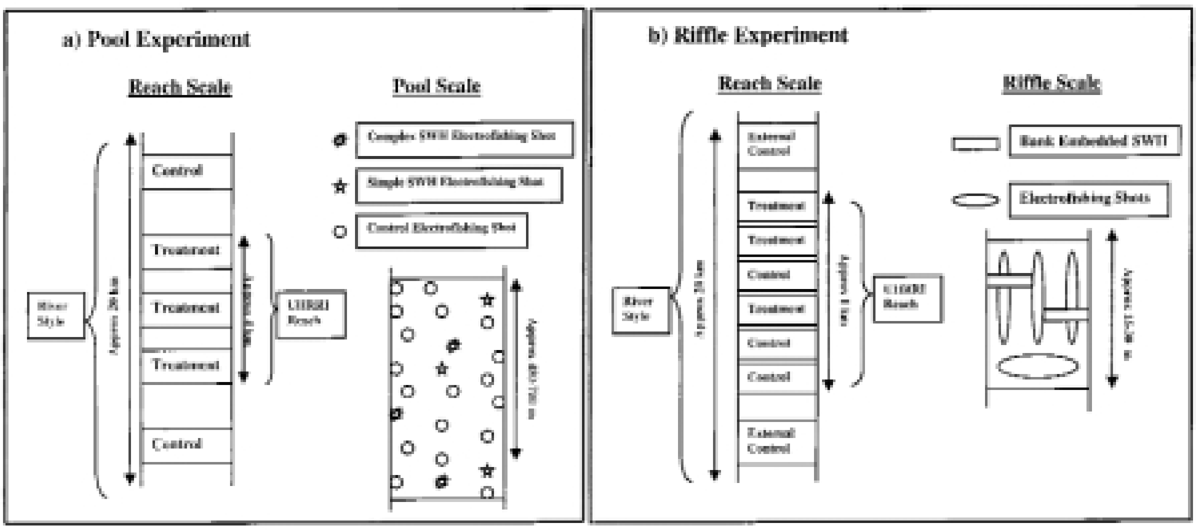

Figure 1. Spatial design for the a) pool and b) riffle experiments. The symbols represent the approximate arrangement of sampling units.

1) Pools

The two main tests of interest for the pool study are: 1) control (i.e. no SWH) *versus* treatment (i.e. SWH) and 2) simple *versus* complex SWH. Simple and complex structures will consist of the same wood frame, with the complex structures in-filled with smaller wood (Brooks & Cohen, this volume). Within the UHRRI reach, three comparable pools (of similar morphology and vegetation) were identified and selected for rehabilitation (i.e. treatment with reintroduced SWH) (Figure 1a). External to the UHRRI reach, in the same river style, two pools of similar morphology and riparian vegetation were selected as controls. Within each treatment pool six woody structures have been introduced, three simple and three complex. Before and after sampling effort in each pool consists of twenty-four shots of one-minute of electricity (on-time), distributed through each pool inclusive of introduced SWH. The controls include both bank and mid-stream electrofishing shots (minimum twenty-four shots). Sampling independence will be maintained by following a sampling routine in which electrofishing never occurs in the same micro-habitat (i.e. bank or mid-stream).

2) Riffles

There are two main experiments in this component; 1) treatment *versus* controls external to UHRRI reach (which should provide a sound test of treatment effect) and 2) internal *versus* external controls. Differences between the performance of internal and external controls tells us about the likely difficulties caused by non-independence of treatment (caused by fish moving between treatments and controls as assessed by fish tagging and directional fyke netting). Six riffles of similar morphology and riparian vegetation were identified in the UHRRI reach (Brooks & Cohen, this volume). Three riffles were randomly selected for rehabilitation and three riffles as controls (Figure 1b). The additional two external controls (of similar morphology and vegetation) were located outside the reach in the same river style. Sampling effort consists of four electrofishing shots in each riffle. The duration of each electrofishing shot and the area sampled vary according to the length of each riffle, but fish captures will later be standardised by length of the riffle and on time electrofishing.

Multiple lines of evidence

The difficulties with the potential lack of independence between control and treatment replicates and replicate SWH units mean that typical statistical models appropriate for such designs (i.e. BACI-designs) cannot be applied simply (Downes *et al*. 2002). However, the intensity of sampling in this experiment (and the two types of controls in the riffle experiment) will permit us to determine whether the expected lack of independence is, indeed, a problem. Presently, most studies either ignore such problems altogether or, like this study, lack the information needed to know the stream distances required between replicates to ensure independence. Additionally, the project is therefore taking a 'multiple lines of evidence approach' (Figure 2) to strengthen the case for testing the effectiveness of adding artificial SWH to a river system. Practically, this means using many different lines of evidence to build up a bigger picture of fish responses and strengthen the conclusions as to the success or otherwise of rehabilitating this reach of the Hunter River for fish.

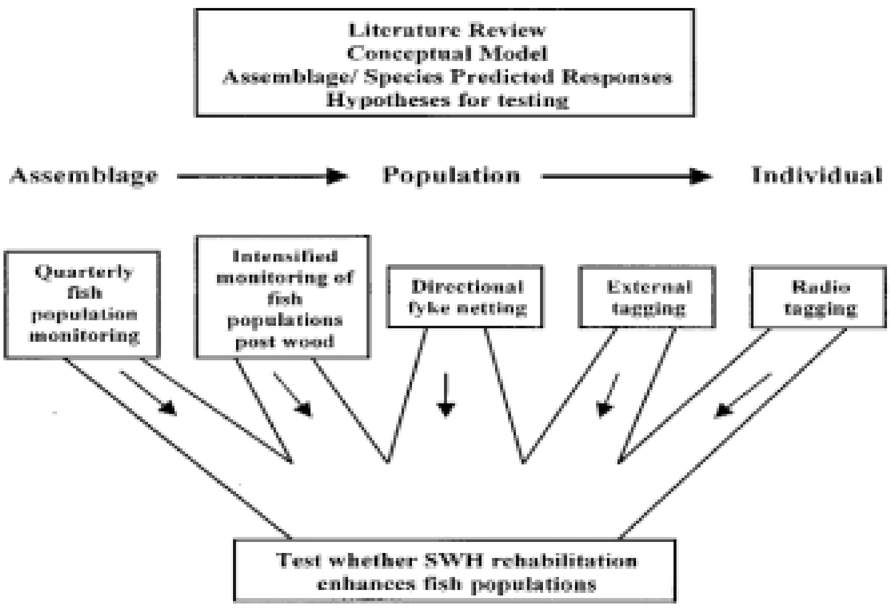

Figure 2. Framework for multiple lines of evidence that will be used to assess the effectiveness of the introduction of Structural Woody Habitat (SWH) for fish.

The basis for and linkage of these multiple lines of evidence will be driven by conceptual models and predictive statements describing the expected responses (or lack of response) for each fish species to the SWH in riffles and pools. *A priori* predictions will be made for fish species occurring in significant numbers. These statements will be based on literature reviews, known movement patterns, known meso/micro-habitats, trophic status, reproductive cycles and other biological characteristics. Riparian vegetation, in-stream habitat and water quality variables (dissolved oxygen, temperature, turbidity, conductivity) will be monitored to document background variation in parameters known to influence fishes. Quarterly fish monitoring (using electrofishing) will be undertaken before and after wood introduction to test for changes in the fish populations within the pools and riffles. Immediately after wood introduction, fish monitoring will be intensified to establish the extent of independence between structural units in the pools (by external tagging), and to gain some idea of the rates of recruitment and succession around them. The project will also involve analysis of movement between pool and riffle units by fish, using directional fyke netting. External tagging will be used to investigate fish retention on the structures, and to determine whether catadromous fish species return to the same structure after spawning. Radio tracking will be employed to monitor rates of movement of individual fish through the reach, and to gain some insight into the independence of individual pool structures and specific usage of the SWH by particular fish.

Fish assemblages in the study reach

A priori species level predictions will be compared with actual fish responses. Around SWH in pools there is expected to be an increase in abundance of Australian bass *(Macquaria novemaculeata)*, common carp *(Cyprinus carpio)*, Cox's gudgeon *(Gobiomorphus coxii)*, larger specimens of long-finned eel *(Anguilla reindhardtii)*, and sea mullet *(Mugil cephalus)*. It is predicted that the complex SWH will support a more diverse and abundant fish assemblage than the simple structures. In the treated riffles, we predict that geomorphological changes (e.g. scour) after SWH introduction will increase diversity of hydraulic habitats. It is expected that this will increase fish diversity by changing the relative abundance of species and increasing species richness. It is predicted that Australian bass *(Macquaria novemaculeata)*, and eel-tailed catfish *(Tandanus tandanus)* will become more abundant in the riffles while Cox's gudgeon *(Gobiomorphus coxii)* and long-finned eel *(Anguilla reindhardti)* will remain relatively abundant.

Sampling of fish populations prior to the introduction of SWH has been done between October 2003 and April 2004. Data combined from the three sampling episodes in this nine month period give a good indication of the relative abundance of species. In the pools gambusia *(Gambusia holbrooki)* was the most common fish species (55.8% of the total number), although these fish were largely unaffected by boat electrofishing and counts were based on visual estimates of fish observed at the surface. Other common species found over all sampling times were sea mullet *(Mugil cephalus)* 20.4%, Cox's gudgeon *(Gobiomorphus coxii)* 7.2%, common carp *(Cyprinus carpio)* 7.1%, long-finned eel *(Anguilla reinhardtii)* 2.9%, and Australian bass *(Macquaria novemaculeata)* 2.8%. The riffles are largely dominated by long-finned eels *(Anguilla reinhardtii)* 44.6% and Cox's gudgeon *(Gobiomorphus coxii)* 32.7%, together comprising over 75% of the fish sampled. Other species of fish sampled in lesser abundance throughout the reach were: goldfish *(Carassius auratus)*, empire gudgeon *(Hypseleotris compressa)*, freshwater herring *(Potamalosa richmondia)*, Australian smelt *(Retropinna semoni)* and eel-tailed catfish *(Tandanus tandanus)*.

Discussion and Conclusion

Wood has been reported as a limiting factor for fishes in many rivers (Gregory 2003). Introducing SWH may be a useful tool for rehabilitating rivers, especially those with little or no riparian vegetation and therefore little opportunity for natural recruitment of wood and litter. Studies of the efficacy of rehabilitation efforts are rarely planned to satisfy concerns about experimental design and statistical examination of field data. For example, the lack of replication across several rivers in the Hunter River program raises important methodological concerns about the spatially confounded nature of linear systems such as rivers. Real life limitations on rehabilitation projects may prevent the use of robust statistical designs. It is, however, necessary to monitor and rigorously evaluate rehabilitation projects to determine the extent of success or otherwise. It is likely that as more river rehabilitation projects are developed in Australia and around the world these issues of experimental design and strength of evidence will increasingly emerge. Constraints arising from most rehabilitation projects are likely to necessitate innovative approaches. The 'multiple lines of evidence' approach used in this study has potential to be used in many similar projects.

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