Restoring structural woody habitat in the River Murray

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Abstract

To assist in improving the health of the River Murray, restoring woody habitat to quantities required to sustain its biodiversity has been recommended. To provide knowledge for this process, a program commenced in 1999 to reintroduce woody habitat within an experimental framework in the River Murray between Yarrawonga and Tocumwal. Specifically, the program investigated methods for determining where in a river and at what density/configuration woody habitat should be restored to maximise environmental benefits; how this restoration can be undertaken in a large river; and mechanisms for participatory management in restoration.

The results from the experimental reintroduction of woody habitat clearly demonstrated that a reference reach approach to determining the natural load and pattern of woody habitat distribution was valid for planning this woody habitat restoration. The placement of woody habitat in different geomorphological positions influenced the occupation of this habitat by native fish species. The probability that native fish occupy a site increased with woody habitat density at that site. Native fish spatially partitioned the available woody debris habitat based on its geomorphological position. The age of the timber used (green or old) did not influence the use of the reintroduced woody habitat by fish, macroinvertebrates or algae. There has been no movement of the placed woody habitat since reintroduction in 2000, nor any adverse bank or bed erosion. This information can be incorporated into a bioeconomic analysis that allows river restoration to be placed within a cost–benefit framework. Simple engineering and machinery recovery techniques can be used to effectively place woody habitat in large rivers with minimal environmental impact. Involvement and ownership by local agencies is useful for establishing community support and providing efficiency in implementing restoration.

Introduction

Structural woody habitat (SWH) plays a significant role in structuring community composition and primary production in river ecosystems and forms an integral part of the habitat structure of many freshwater systems. SWH consists of trunks, branches and root masses of vegetation (Stevens 1997) that have fallen into the river channel through a variety of processes including windthrow, bank erosion and limb shedding (Murphy & Koski 1989; Marsh *et al.* 1999). SWH is commonly termed 'large woody debris' in the literature.
The outcomes from a recent workshop to review guidelines for managing wood in Australian streams (Cottingham *et al.* 2003) recommended that that term be revised.
SWH has been used to avoid any negative connotations associated with the use of the term 'debris' and to describe its ecological importance (Koehn *et al.* 2004).

The presence of SWH in rivers influences the physical conditions and morphology of river channels (Gregory & Davis 1992; Gippel 1995; Keller & Macdonald 1995; Brooks 1999) and provides organic carbon to streams, both from the SWH itself and by trapping other organic matter (Bilby & Likens 1980; Bilby & Ward 1991). SWH through its decomposition and the decomposition of the other trapped organic matter, also affects the in-stream level of other nutrients including nitrogen and phosphorus (Aumen *et al.* 1990). Organisms that use SWH as habitat structures or refugia include fish, birds, amphibians, macroinvertebrates and algae. Invertebrates use SWH as a substrate (Hax and Golloday 1998) and as a food source (Benke *et al.* 1985; O'Connor 1991; Boulton & Lloyd 1991). Freshwater fish use SWH as foraging sites, spawning substrates, protection from river currents, and camouflage from predators or prey (Lehtinen *et al.* 1997;

Angermeier & Karr 1984; Tillma *et al.* 1998; Flebbe 1999; Horan *et al.* 2000; Crook & Robertson 1999; Roni & Quinn 2001; Quist & Guy 2001).

SWH has been extensively removed from many Australian rivers, particularly in the Murray-Darling Basin, for navigation and water passage purposes (Mudie 1961; Phillips 1972; Hall & Mudie 1975; Treadwell *et al.* 1999). The removal of SWH is now recognised as a threat to native freshwater fish species (e.g. Cadwallader 1978; Koehn & O'Connor 1990; Wager & Jackson 1993; Kearney *et al.* 1999), and reintroducing SWH back to these rivers has been recommended as a restoration measure (e.g. Lloyd & Walker 1986; Lawrence 1991; Koehn 1994; Gippel *et al.* 1996a; Gippel *et al.* 1996b). The assumption that organisms that rely upon SWH in these rivers will return with its replacement, however, is unproven.

The adoption of SWH restoration (referred to as resnagging) in large lowland rivers has been hampered by a lack of technical information on where in the river system SWH should be placed to maximise its restoration benefit, particularly for native fish. As a first step in providing this information, Treadwell (1999) provided guidelines for managing SWH restoration programs in Australian rivers. In this study, we have experimentally tested some of these recommendations to provide evidence for the benefits of resnagging; the results are summarised in this paper. The study concentrated on three key areas: the application of reference reach analysis for determining where to place SWH in large lowland rivers; the response of native fish to the creation of SWH through resnagging; and the planning and agency compliance required to undertake resnagging.

The study was undertaken on the River Murray between Yarrawonga and Cobram. This reach was deliberately chosen because there is no record of SWH removal and this allowed the pattern and distribution of SWH in this reach to be quantified. The Yarrawonga–Cobram reach also supports an abundant and healthy native fish population which could maximise the chance of being able to measure a fish response within the three years of the study. In a degraded river, where native fish populations are low in abundance, a delay in the fish fauna response would be expected.

Project planning and management

The project planning and management process developed from this study is summarised in **Figure 1**.

Clearly specifying the objectives and intended targets from river restoration is a critical first step in implementing successful river restoration (Slaney & Zaldokas 1997; Rutherfurd *et al.* 2000). In the Murray-Darling Basin, there is generally more than one environmental stressor affecting rivers in need of restoration. It is important that these stressors be ranked in order of importance (Koehn *et al.* 1999; Thoms *et al.* 2000) and that the consequences of each of these stressors be evaluated against any intended restoration.

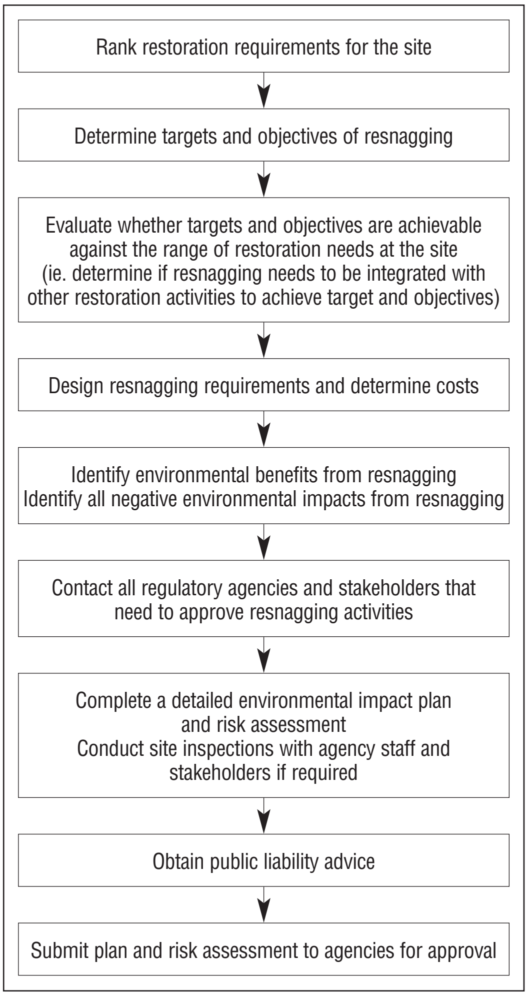

Figure 1. Project planning and management sequence developed from this study for obtaining approval by relevant authorities for undertaking large-scale resnagging

For example, if the intention is to restore physical habitat through resnagging for native fish species, and there are other stressors such as thermal pollution having an impact upon the area to be restored, then the influence that the thermal pollution will have on the outcome of the resnagging should be evaluated. Identifying the likely effects that other stressors will have on the outcomes from the resnagging will allow more realistic and achievable objectives and targets to be set.

Once the objectives and targets have been set, the design criteria for the resnagging can be undertaken and balanced against the resources available.

Large-scale river rehabilitation works generally require the involvement and approval of a variety of agencies. It is important to review all the literature on local legislation and policy, relevant to the area. For example, to undertake SWH restoration in this project we required approval from the following agencies:

- **Parks Victoria** — Parks Victoria is responsible for the management of the State Forest adjoining the sites resnagged along the southern bank (Victorian side of the River Murray). Permission was required from this organisation for heavy vehicle and machinery access at these sites.
- **Department of Infrastructure, Planning and Natural Resources (formerly Department of Land and Water Conservation)** — The Department of Infrastructure, Planning and Natural Resources is responsible for the management of the riparian zone (50 m strip either side of the river channel), river bank and river bed in this reach of the River Murray. An Environmental Impact Assessment was required detailing the potential environmental impacts from the resnagging activities.
- **New South Wales Fisheries** — An impact statement under the NSW Fisheries legislation was required, documenting any impacts on threatened species in the region.
- **New South Wales Environment Protection Authority** — An impact statement under the NSW Environment Protection Authority legislation was required, documenting any adverse impacts on water quality as a consequence of the resnagging operation.
- **New South Wales Waterways** — Approval was required under the NSW Waterways Act, with regard to the maintenance of a navigable channel. This agency is also responsible for administering river closure that was required during the resnagging operation.
- **Yorta Yorta Nation** — Permission was required, under the Native Title Act, from the Yorta Yorta Nation which had an application claiming Native Title for this area at the time.

To facilitate this process, a document was prepared that identified all likely environmental benefits and negative impacts from resnagging. This provided each agency with the relevant supporting material to assess the application for resnagging, and all necessary material for preparing the specific documents these agencies required as part of their approval and permitting process. Public liability should also be included in this documentation and public liability officers from the responsible authorities should also be contacted for advice and assessment of liability. To undertake resnagging in the River Murray, notification about resnagging activities was required in the local newspaper and signs had to be erected indicating where resnagging sites were located.

Technique for resnagging large rivers

A technique of cable dragging was developed for this project, as river size, bank height and water depth constrained the application of the other techniques used when resnagging smaller streams (e.g. excavator placement). The technique is a simple modification of retrieval techniques used in forest harvesting. The SWH items are placed on the bank of a site. A cable is laid from the SWH item to the other bank where it runs through a fixed pulley and is returned back across the river to the SWH item. One end of the cable is then attached to the SWH item with a quick release retrieval mechanism (**Figure 2**).

The other end of the cable is then simply pulled by a tractor/dozer/excavator/winch until the SWH item is dragged into the desired position in the river. The quick release mechanism is activated and the cable is retrieved by pulling back on the cable (**Figure 3**).

Figure 2. Quick release mechanism and cut used for easily retrieving the cable when the SWH item is in the correct position

Use of cost–benefit modelling

Cost–benefit analysis is a particularly useful tool for maximising environmental outcomes for the dollars spent (Choquenot & Hone 2002). In this study, two models were developed to allow cost–benefit analysis to be undertaken; one examined costs and benefits at the landscape scale and the other examined them at a local scale. The landscape model clearly identified that resnagging sites within the colonisation range of a source population is critical to the rehabilitated site being occupied by fish. At the local scale, the cost–benefit analysis undertaken has identified the important trade-offs that need to be considered when planning any resnagging activity. The major costs identified in this analysis are the fixed costs associated with the relocation of equipment and set-up time required at new sites. Planning needs to evaluate the benefits from resnagging a greater number of sites or fewer sites at higher densities, and the costs associated with doing this. As an example, the data collected from this study was used to construct a model that allowed the fish population benefit (expressed as the probability of a recovering population of trout cod falling below 50 individuals in a 10 km area during a 50 year time period) to be evaluated against the costs of resnagging either 10, 20 or 40 sites in a 10 km area at different SWH densities (**Figure 4**).

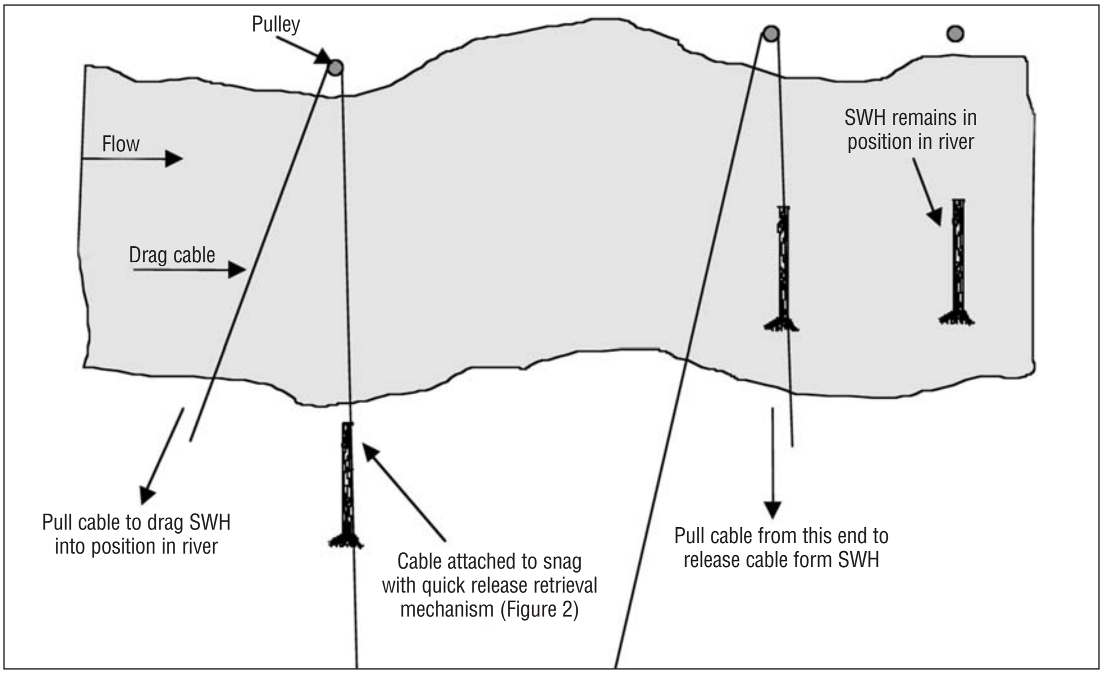

Figure 3. Cable dragging technique for placing snags

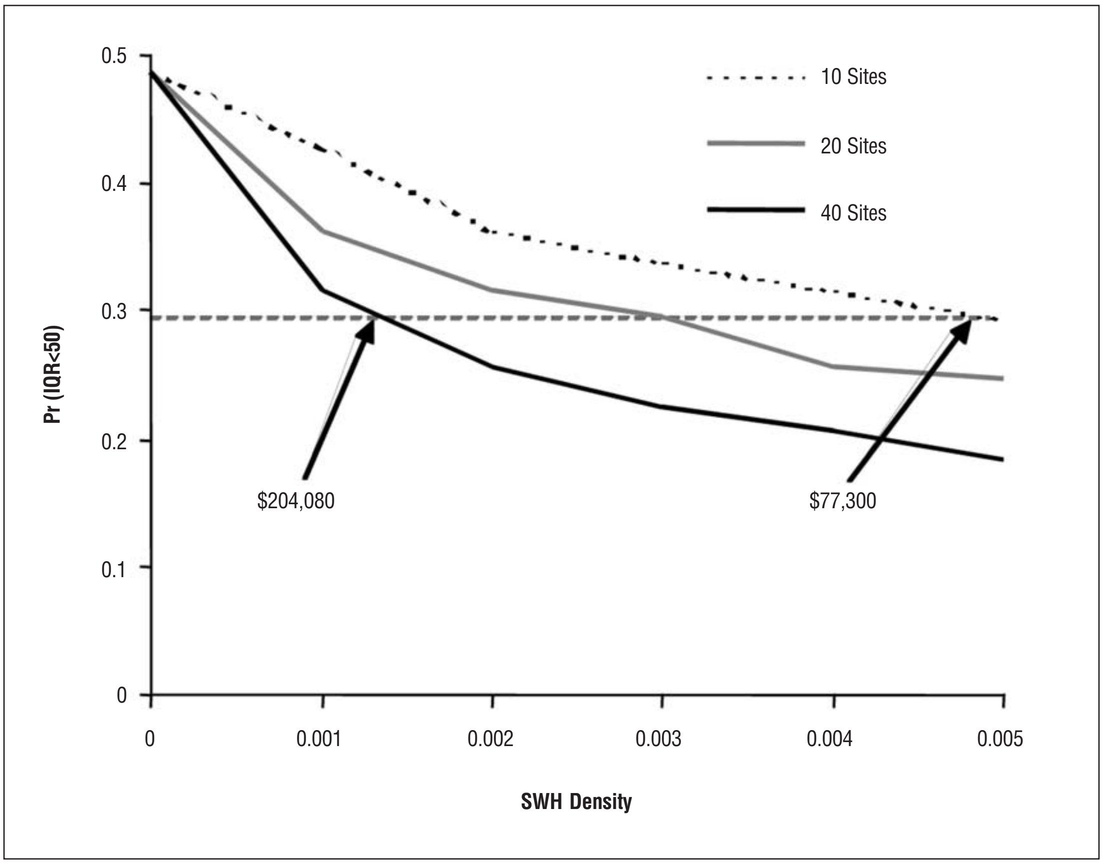

Figure 4. An example of simple cost–benefit modelling that can assist the process of determining the most appropriate number of sites and density of resnagging (source: Nicol et al. 2002)

In this simple example, the benefit achieved by resnagging 40 sites at 0.0013 SWH/m^2 was equivalent to the benefit from resnagging 10 sites at 0.0049 SWH/m^2. However, the costs of these two scenarios are significantly different: $204,080 to resnag 40 sites at a lower density and $77,300 to resnag the 10 sites at a greater density. Clearly in this example, if the costs associated with getting access and timber to sites is equal then resnagging 10 sites at a higher density is a more efficient use of resources to achieve the desired outcome (i.e. to accept a 30% chance that the trout cod population may fall below 50 individuals over the next 50 years). The models developed and scenarios modelled in this study are transferable to any resnagging scenario.

Use of reference reaches

SWH distribution

Treadwell (1999) recommend that sufficient SWH material should be reintroduced to ensure loadings are comparable to the natural load of the river. When this information is lacking, it can be estimated by measuring the amounts of wood present in un-degraded reaches of similar stream types (reference reaches) or from historical documents available from local river management authorities and State agencies that detail the amount of SWH removed from particular river reaches.

Undertaking a reference reach analysis in this study allowed the natural distribution and abundance of SWH to be quantified. Not only did this analysis provide an average density for SWH in this reach of the River Murray, but also it provided a detailed description of where in the channel this SWH accumulated. To describe the distribution of SWH in this reach a hierarchical approach was adopted that examined the distribution at multiple scales (**Figure 5**).

Whole-of-reach scale

At the whole-of-reach scale, SWH was distributed uniformly along the reach in clusters, with individual pieces within a cluster predominantly close to the bank and mostly at angles 90º or less to the flow. This uniform pattern can be related to uniformity of several processes at the reach scale. The flow regime, sediment regime, geologic history, channel boundary material (Rutherfurd 1994) and riparian vegetation (MDBC 1990) are similar throughout the study reach. Consequently, the processes that affect the recruitment and fate of SWH — essentially the bank erosion rate and stream power — may be expected to be similar for the whole of the reach and result in a uniform pattern of distribution of SWH at reach scale.

Between-meander scale

When data were considered at the smaller meander scale, it became apparent that associations existed between channel geomorphology and SWH distribution that were not evident at the reach scale. First, straights had similar amounts of SWH on each side of the channel, whereas bends had twice as much SWH on the outer bank as on the inner bank. Second, SWH was on average further from the bank in meanders with a tighter curvature than it was in more gently curving meanders. Both of these can be related to stream energy patterns at the meander scale.

Within-meander scale

When the data were considered at a finer scale (within-meander) it became apparent that the proportional distributions of SWH within a meander were different. At this scale SWH characteristics including angle to flow and distance from bank varied according to the position within the bend. These associations were directly related to variations in stream energy levels along the length of the meander.

It is clear from this study that the scale at which reference reach analysis is undertaken influences the results. Careful consideration of the scale at which a study is undertaken is important, not only in the design of the study but also in the interpretation of the results. In this study the data were collected from low-level aerial photography and recorded in such a way that they could be examined at more than one scale.

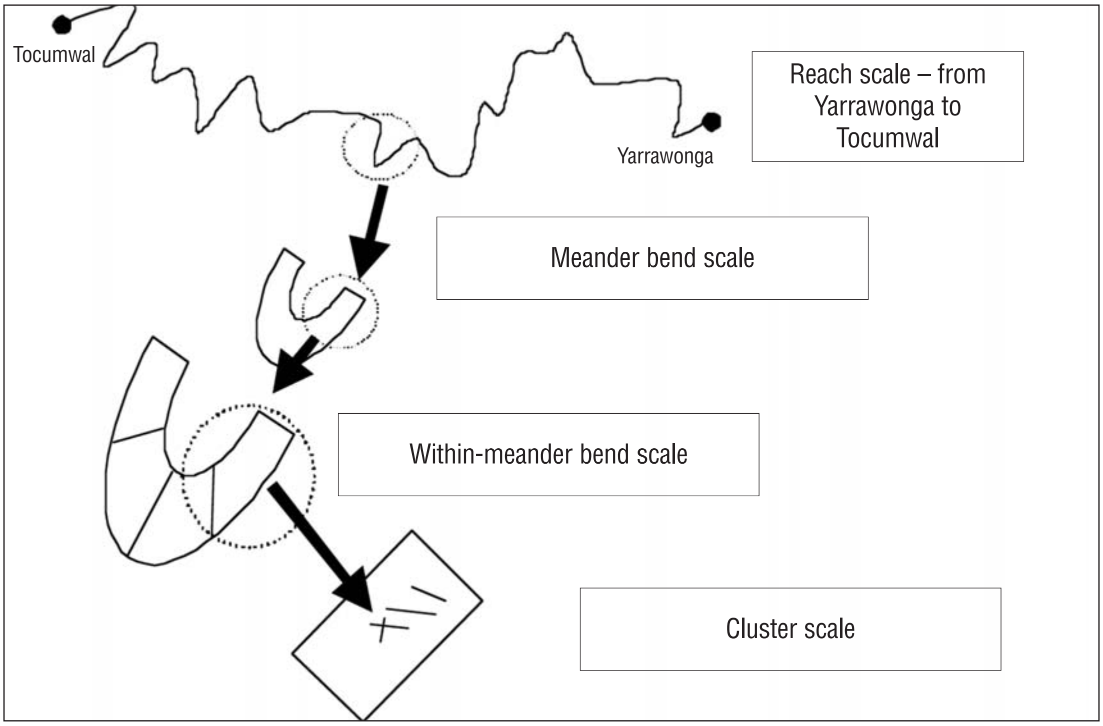

Figure 5. Diagrammatic representation of the multiple scales used in this study of distribution of SWH

This approach added little or no time to the data collection process and allowed associations between geomorphology and SWH to be demonstrated at three different scales. Clearly, reference reach analysis could easily apply a multi-scale approach without increasing the overall cost of the study, provided that the scales of the study are considered before data collection is undertaken.

The results presented suggest that in a large, low-gradient, meandering river, SWH reintroduction needs to be managed at the scale of individual meander bends. The results indicate that SWH should be positioned in clusters that are relatively close to riverbanks, in the high-energy eroding parts of bends, and at a variety of angles between 0° and 90° to stream flow.

The general rule for the recommended volume of wood in a river is around 0.01 m^3 for every square metre of channel bed area (Treadwell 1999), similar to that measured in this study. This amount could be several magnitudes higher or lower at the cluster scale, depending on the specific location within different meanders.

Fish use of SWH habitats

Reference reach analysis was also applied to identify any relationship between the spatial distribution of native fish and river planform. The analysis of fish distribution was matched to the scales used to identify the SWH distribution. In this study, the analysis identified the meander types and positions within a meander bend that sustained the highest abundance of native fish.

To determine whether the distribution of native fish was related to the distribution of SWH or river planform, fish were surveyed at sites in the study reach with differing densities of SWH and at sites with differing river planform characteristics. Analysis of this data identified that native fish were more abundant in meanders with a moderate to tight curvature and at bend positions that abutted eroding banks. The analysis also identified that different species used different types of SWH accumulation. In summary, trout cod and Murray cod were relatively more abundant in SWH clusters at the start and ends of meanders. Golden perch were less specific in their distribution, using SWH accumulation across the entire length of a meander. All species were more abundant where SWH had accumulated into areas of higher density. This coincided with sites on eroding banks. Within these sites, Murray cod were more abundant in the area close to the bank (within 15 m) and trout cod and golden perch were equally abundant across the sites. SWH items with hollows were important for Murray cod and trout cod. The position and orientation of SWH were important for all species. SWH items that were moderately angled, close to the bank, that were long and relatively complex, and that created velocity shelters, were those most commonly used by fish.

This information was used in conjunction with the SWH distribution data to develop suitable designs for resnagging sites within this reach, demonstrating that the reference reach concept (Treadwell 1999; Koehn *et al.* 2000) is a scientifically sound methodology to apply when planning resnagging activities.

Type and structure of wood used

Green versus dry timber

Colonisation rates by macroinvertebrate and algal species were measured over a 32-day period to determine preferences for certain wood types in different areas of a river (a SWH-rich area and a SWH-poor area). The wood types used were green wood (i.e. wood from a live tree that had freshly fallen), dry wood (i.e. wood that had been dead for an extended period of time) and conditioned wood (i.e. dry wood that had been submerged for an extended period of time). Macroinvertebrates were found to colonise conditioned wood more rapidly than green or dry wood (**Figure 6**), and assemblage structure varied significantly over the sampling period (**Figure 7**).

Copepods were well represented in the early samples, but were replaced with large numbers of chironomids by day 32. No differences were recorded between numbers of individuals found on green or dry wood, or between numbers of individuals found between SWH-rich and SWH-poor areas. One hundred species of algae (from seven families) were recorded during the sampling period. Algal species composition on conditioned wood was different from that on green or dry wood.

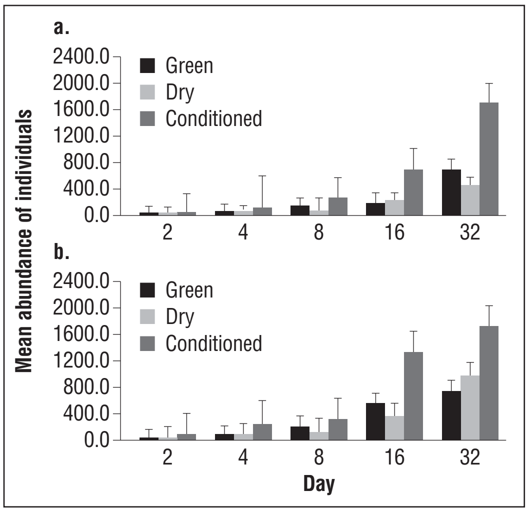

Figure 6. Mean abundances of macroinvertebrates collected on each sampling trip ± 1 S.D. (excluding copepods). Note: 'a'= SWH-rich site, 'b' = SWH-poor site (source: Nicol et al. 2002).

Whilst significant differences between conditioned wood and green and dry wood remained after 32 days, this is not surprising given the short timeframe of the study.
The conditioned wood was scrubbed with a wire brush before being used in this study, but there is a high likelihood that conditioned timber would have some residual animals or larvae/eggs on it prior to its placement. The results however indicate that there is little difference in the time taken to establish community composition after SWH introduction, whether using green or dry wood. This has implications for large scale resnagging projects, given that green wood is often a more cost-effective option and more likely to be available than dry wood.

Types of SWH

Observation from fish surveys indicated that fish use obscurely shaped timber. Whilst it may be logistically simpler to transport straight trunks to a site, it is likely that using trees with forks, branches, hollows and root masses will create a greater diversity of habitats.

The use of a range of size classes, including large almost entirely intact trees, is highly recommended. Some very large SWH items are essential for the natural formation of SWH accumulations. Natural SWH items in isolation are often large immobile fallen trees and these items can trap smaller more mobile debris creating aggregations (Abbe & Montgomery 1996; D'Aoust & Millar 1999).

Both Murray cod and trout cod demonstrated a preference for SWH with hollows. Consequently, the selection of SWH items with hollows for resnagging is likely to be beneficial if habitat for these species is being reconstructed.

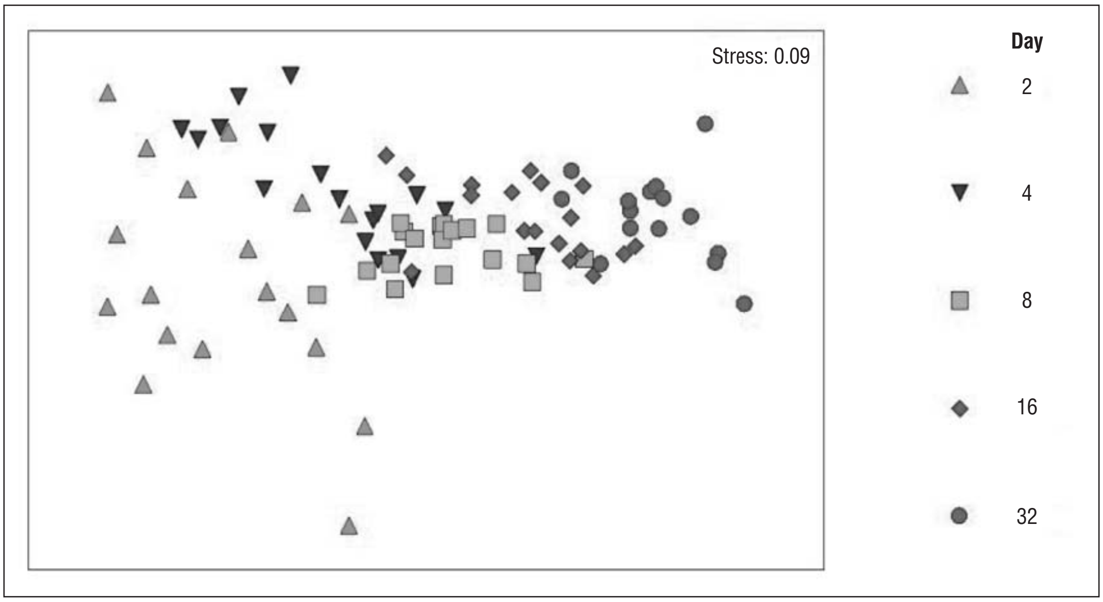

Figure 7. Non-metric multi-dimensional scaling ordination showing change in assemblage structure over the 32-day sampling period (source: Nicol et al. 2002)

Position, density and orientation in channel

To test the findings of the reference reach analysis and to determine whether native fish would use reintroduced SWH, 14 sites were resnagged in the study reach. The results demonstrated that native fish responded positively to the addition of SWH (**Figure 8**). All three native fish targeted (Murray cod, trout cod and golden perch) used the treatment sites within 12 months of the resnagging, with all size classes of each species being represented. The frequency of occurrence of all size classes was consistent with that observed in the reference sites (**Figure 9).**

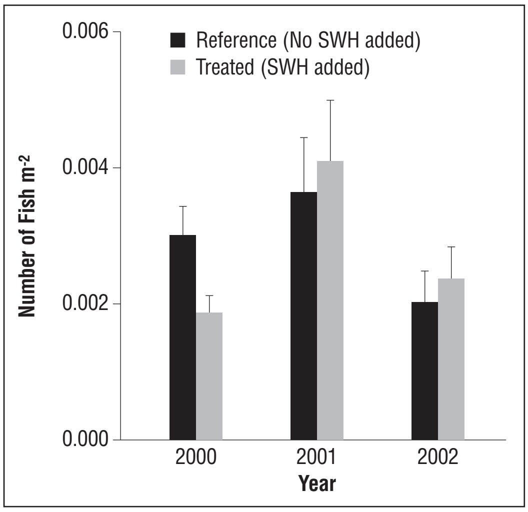

Figure 8. Total numbers of native fish caught ± 95% confidence interval (CI), at untreated (no SWH additions) and treated (SWH additions) sites before and after the addition of SWH (resnagging). Note untreated and treated sites were significantly different before resnagging but were not significantly different after resnagging (source: Nicol et al. 2002)

Native fish also responded positively to the density of SWH in a site. In the experimental trial we deliberately maintained an equal density of SWH within the 2700 m² area of each site, but manipulated the placement of SWH within each site. At four of the sites, SWH was positioned so that its density was highest at the downstream end of the site. Similarly four sites were designed so that the density was higher at the upstream end, and at four sites the SWH was placed so that the density was even across the entire site. The number of fish at sites where the SWH had been placed into areas of higher density in either the downstream or upstream sector was higher than that observed in the sites where the SWH had been distributed evenly across the site (**Figure 10**). This result suggests that creating local areas of higher density of SWH will provide greater benefit for native fish.

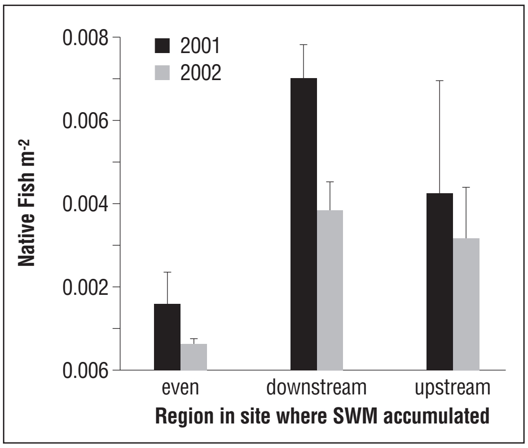

Figure 10. The density of fish ± 95% CI recorded in sites where the density of SWH was manipulated. At even sites the density of SWH was distributed equally across the site. At the other sites the density of SWH was greater in the downstream or upstream end of the site. (Source: Nicol et al. 2002.)

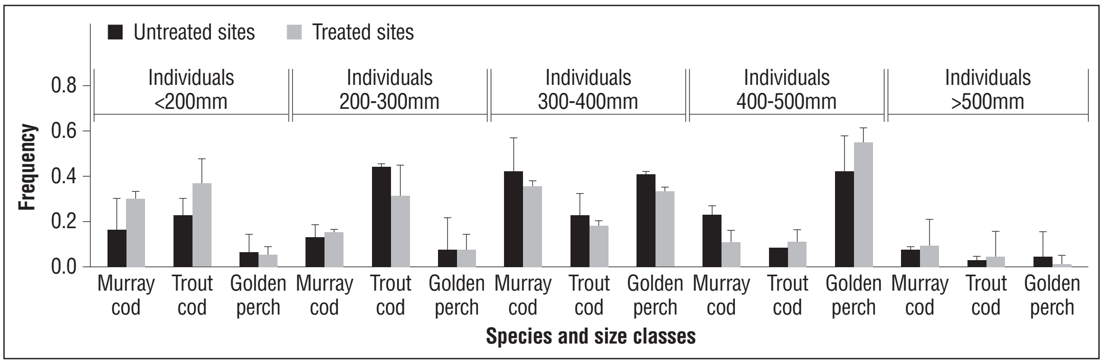

Figure 9. Mean numbers of individuals in each size class ± 95% CI at resnagging and untreated sites (reference sites) for Murray cod, trout cod and golden perch (source: Nicol et al. 2002)

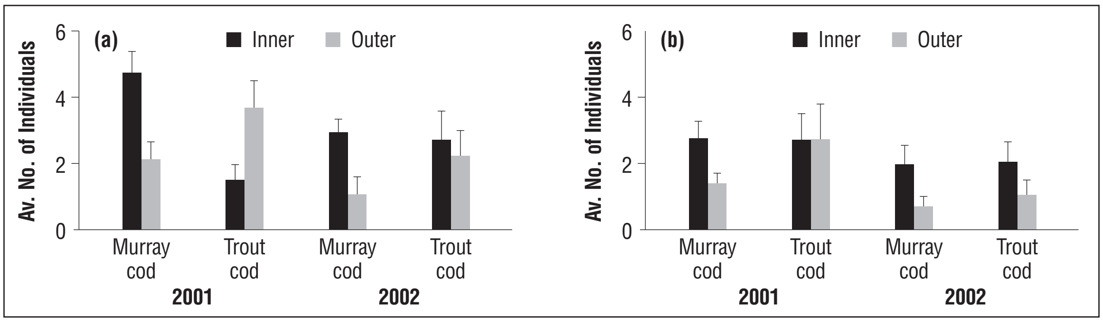

Figure 11. The average number of individuals caught ± 95% CI in the inner (next to bank) area of sites and outer (>15 m from bank) area of sites at (a) reference sites and (b) resnagging sites (source: Nicol et al. 2002)

The optimal location for SWH placements from the bank was dependent upon the target species (**Figure 11**).

If resnagging activities are targeting Murray cod then maximum benefit is likely to be obtained by resnagging within 15m of the bank. Resnagging this inner area will also deliver benefits for trout cod. The resnagging of outer areas will only deliver benefits for trout cod and not Murray cod.

SWH movement

Low-level aerial photos were taken of each of the resnagging sites in 2001 and compared to the location records from 2000 to determine whether the placed SWH items had undergone any substantial movement. These photographs were analyzed at 100X magnification. There was no significant movement recorded at any of the resnagging sites. The Yarrawonga–Tocumwal reach experienced flows in excess of 12,000 ML/day after the SWH items were placed in each site. The lack of movement recorded suggests that these items will be stable at flows up to this level.

Whilst undertaking the resnagging at each site, a selection of SWH items that were dry (i.e. fallen trees that had dried to an extent where their specific gravity was lower than that of green timber) were tested for their suitability as resnagging timber. All of these items were buoyant and required securing to avoid them floating downstream. If dry timber is to be used in resnagging activities then ballasting may need to be considered.

Bank erosion

The banks at each site resnagged and at reference sites were GPS-surveyed prior to the addition of the SWH and again in 2001. There were no recorded adverse effects of bank erosion from resnagging works. Where erosion did occur, it was highly localised and inconsequential at any relevant scale. The SWH were oriented within a downstream arc from perpendicular to parallel in such a way that direction of flow was diverted away from the bank. No snags were oriented in an upstream direction. The use of heavy machinery to place snags in the sites was restricted to sites where the risk of any bank erosion was low. Potential sites were inspected and approved by the land management officer from Parks Victoria, and any disturbances to the bank were subject to remedial works as directed by this officer.

In summary

In this project we set out with the clear objectives of determining whether native fish would use added SWH habitat and whether undertaking resnagging was achievable in large rivers. Our conclusions from this study are positive. Native fish actively used this newly added habitat and the techniques used to plan and implement this type of restoration in a large lowland river were cost-effective.

There remain, however, key questions that need to be addressed. Understanding how populations respond to resnagging is crucial. The current study asked questions about use of habitat and did not attempt to understand whether the increase in the number of native fish occupying each site resnagged was related to immigration and recruitment into the population or just redistribution of the existing population. The objectives under the Native Fish Strategy (MDBC 2004) clearly state that the intention of any restoration is to improve the viability of native fish populations. Increasing the population growth of native fish populations will be an important component in achieving this. Consequently, we need to understand the importance of resnagging in improving population growth, so that future investment in resnagging can be evaluated against other restoration activities (e.g. fishways) and its contribution to integrated river restoration can be evaluated.

Most restoration programs tend to occur on a reach-by-reach basis rather than a whole-of-basin basis and consequently including replication in the experimental design and monitoring of these restorations is likely to be difficult. Consequently, we need to consider a range of monitoring designs that are not dependent upon replication to measure their desired goals. This is a developing area of statistics in applied ecology and we need to resource its development. We also need to develop guidelines for monitoring resnagging so that results from different programs are comparable. If we are able to develop these guidelines then we should, by undertaking meta-analysis, be able to establish rules of thumb that are transferable across different river types and that can achieve both geomorphic and conservation objectives.

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