RIPARIAN ECOSYSTEMS AND BUFFERS: MULTI-SCALE STRUCTURE, FUNCTION, AND MANAGEMENT
AWRA SUMMER SPECIALTY CONFERENCE
Olympic Valley, California
June 28-30, 2004

PREDICTING THE RECRUITMENT OF LARGE WOODY DEBRIS THROUGHOUT A WATERSHED

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ABSTRACT: Information about the spatial distribution of riparian vegetation, and the ecosystem services it provides, is required to prioritise the protection and restoration of riparian zones within watersheds. Large woody debris performs a range of fluvial geomorphic and ecological functions within streams. This paper describes a new technique for estimating how much large woody debris is provided by riparian vegetation distributed throughout a semi-arid watershed in Queensland, Australia. The technique uses fieldwork combined with a vegetation classification derived from medium resolution satellite imagery to identify four different types of riparian vegetation (woodland, closed forest etc) throughout the watershed. The three attributes of each vegetation type: number of stems per hectare; mean tree height and mean diameter at breast height, are calculated using field data. These attributes are extrapolated beyond the sampling sites using a vegetation classification that was generated from satellite imagery. These attributes are then used to calculate the amount of large woody debris produced by the riparian vegetation. An independent set of field data is used to assess the accuracy of the vegetation classification and to assess the reliability of the attributes predicted by the classification. Results are presented for the whole watershed with discussion on reliability of index results and the potential to use this approach to prioritise the protection and restoration of riparian zones.
KEY TERMS: large woody debris, aquatic ecology, watersheds, riparian zones, spatial extrapolation

INTRODUCTION

Historically large woody debris (LWD) was considered a nuisance and programs were put in place to remove LWD to improve the navigability of rivers and reduce flooding (Gurnell *et al*., 2002). In more recent times hydrologists, ecologists and resource managers have come to recognise the importance of LWD in riparian systems. Numerous studies have been undertaken examining the role of LWD in fluvial geomorphology (Gurnell *et al*., 2002)and stream ecology (Crook and Robertson, 1999).

LWD influences fluvial geomorphology at a range of scales in riparian systems. At the floodplain scale LWD can influence channel formation and direction, and potentially improve bank stability by reducing near-bank flow velocity (Abernethy and Rutherfurd, 1998). At the pool-riffle scale the influence of LWD on hydraulics can lead to a range of hydraulic conditions including areas of turbulent flow, accelerated flow and areas of slack water, these localised variations in hydraulic conditions often result in the presence of patches of different substrate such as silt, sand and fine gravel immediately downstream of LWD (Gurnell *et al*., 2002). The variety of flow conditions and variety of substrates generated by LWD can improve the range of habitat available for aquatic biota (Crook *et al*., 1999).

LWD provides a range of terrestrial and aquatic ecological functions. Terrestrial functions include providing habitat for mammals, birds and herpetofauna, and providing food and habitat for the larval stages of many insects (Jansen and Robertson, 2001). Aquatic ecological functions include providing a stable substrate for biofilms to grow on, protecting riverine fish species from avian predation, and providing egg-laying sites for various fish species (Crook *et al*., 1999).

LWD is particularly important in the aquatic ecology of semi-arid areas, where highly variable stream flow can result in large rivers being reduced to a series of isolated water holes during dry periods. During such dry periods the waterholes act as refugia for the aquatic ecosystems of these rivers. Consequently the presence of LWD in waterholes is even more important to protect fish and other aquatic organisms from terrestrial predators (Crook *et al*., 1999). The fact that some waterholes are initiated by the hydraulic effects of LWD (Knighton and Nanson, 2000) further emphasises the importance of LWD in semi-arid systems.

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Established woody vegetation is required to generate LWD. Consequently riparian management strategies aimed at maintaining levels of LWD within stream networks fall into two categories, protection of existing vegetation that is capable of producing LWD, and LWD replacement. The protection of existing vegetation is the preferable management option, because LWD replacement, whilst effective (Gerhard and Reich, 2000), can be very costly to implement at large scales. Planting trees in riparian zones has the long term effect of generating LWD to the stream. However the timescales involved for trees to reach maturity and begin large wood generation are large (decades).

The management of LWD at a whole-of-watershed scale requires spatial information about the presence or absence of riparian vegetation throughout the stream network, as well as information about the amount of LWD being generated by each type of riparian vegetation. The approach described in this study combines field data, a vegetation classification and a simple model to estimate the amount of LWD being generated by stands of riparian vegetation throughout a watershed, it does not account for the transport or fate of the LWD after it has been generated.

METHODS

Study Area

The study was conducted in the Nogoa sub-catchment of the Fitzroy watershed in Queensland, Australia (Figure 1). The climate in the study area is hot and semi-arid. The predominant land uses within the study area are grazing, dry land cropping, and irrigated cropping. The terrain typically has very low relief. Consequently the fluvial geomorphology is typical of a semi-arid, lowland river, with very low channel slopes throughout the watershed. The region was extensively cleared in the 1960s and 1970s but some portions of remnant riparian vegetation remain along the larger rivers.

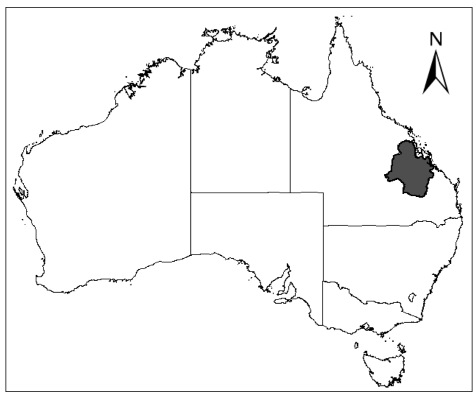

Figure 1. Map of Australia, Fitzroy watershed shown in dark grey

Field Data

Fieldwork was undertaken at 38 sites to establish the relationship between vegetation structural classes and the volume of standing wood per hectare. The vegetation structural classification described in Specht (1970) was used to classify the vegetation observed in the riparian zones into the following classes: closed forest; open forest; woodland and open woodland. The volume of standing timber per tree $wood_T$ was calculated using the diameter at breast height (DBH) the height of the tree (TH) according to equation (1).

$$wood_T = \left(\pi \times \left(\frac{DBH}{2} \right)^2 \right) \times TH \qquad (1)$$

The amount of standing timber per hectare $wood_H$ for that vegetation class at that site was then calculated by multiplying the volume of wood for each tree ($wood_T$) by the number of trees per hectare (λ) for each vegetation class at every site. The field sites were divided into two sets, a calibration set and an evaluation set so that the accuracy of the spatial extrapolation technique could be assessed. The range of standing timber volumes observed at the calibration sites are shown in Table 1.

Table 1. $Wood_H$ values (m^3 ha^{-1}) assigned to each class based on calibration set of field data

Vegetation Class	Median	75th percentile	25th percentile
Closed Forest	136.2	195.0	49.2
Open Forest	62.2	185.4	28.2
Woodland	40.8	98.5	16.2
Open Woodland	23.5	90.3	3.8

Remote Sensing Techniques and Image Processing

The vegetation classification was spatially extrapolated across the study area using a classification of satellite imagery. The satellite imagery used in this study had a 15 metre pixel size which enabled the identification of narrow strips of riparian vegetation. For details of the processing of the satellite imagery see the companion paper by Lymburner *et al*. (2004). The satellite image was classified into eight classes: closed forest, open forest, woodland, open woodland, grazing, bare soil, cropping and dams. Independent sets of field sites were used to calibrate and evaluate the classification of the satellite image. The classification was 96% accurate with some confusion between woodland and open woodland (1 woodland site with sparse canopy cover was misclassified as open woodland), there was no confusion between the four woody vegetation classes and the other classes. The classified image was used to generate a GIS coverage that described the median amount of standing timber for each patch of vegetation, based on the vegetation classification at that patch. For example every patch of woodland present in the image was assigned a standing timber volume of 40.8 $m^3\ ha^{-1}$.

LWD recruitment model,

The LWD recruitment model estimates the large woody debris volume (LWV) ($m^3\ ha^{-1}$) present in the riparian zone as a function of the density of standing timber ($m^3\ h^{-1}$) based on the model Equation 3 as described in (Marsh *et al*., 2001).

$$\mathrm{LWV} = 0.2 \times wood_H - 0.054 \quad (2)$$

This model was developed for *Eucalyptus* sp. dominated vegetation for riparian zones in a wide range of climatic zones including semi-arid. At present the model assumes no transport, but this could be updated once a hydraulic model is available for the study area. It is important to note no direct measurements of LWV were made in this study, the model (Equation 2) was used to predict LWV from standing timber volumes.

The LWV in the channel was calculated by applying the LWD recruitment model described in Equation (2) to the vegetation on both banks adjacent to the channel. To achieve this a focal mean filter was applied to the median volume of $wood_H$. This form of filter writes a value to the central pixel of a 3 pixel x 3 pixel kernel that is the average of the north and south banks if the river is flowing east-west, and vice versa. In the event that the river is running on a diagonal through the kernel the central pixel receives a value that is the average of all four (north, east, south and west) pixels. The LWD recruitment model was applied to the results of this filter to generate a coverage showing the LWV in the channel and in the riparian vegetation adjacent to the channel Figure 2.

RESULTS

An illustrative sample of the LWD volume (LWV) for a section of the study area are shown in Figure 2.

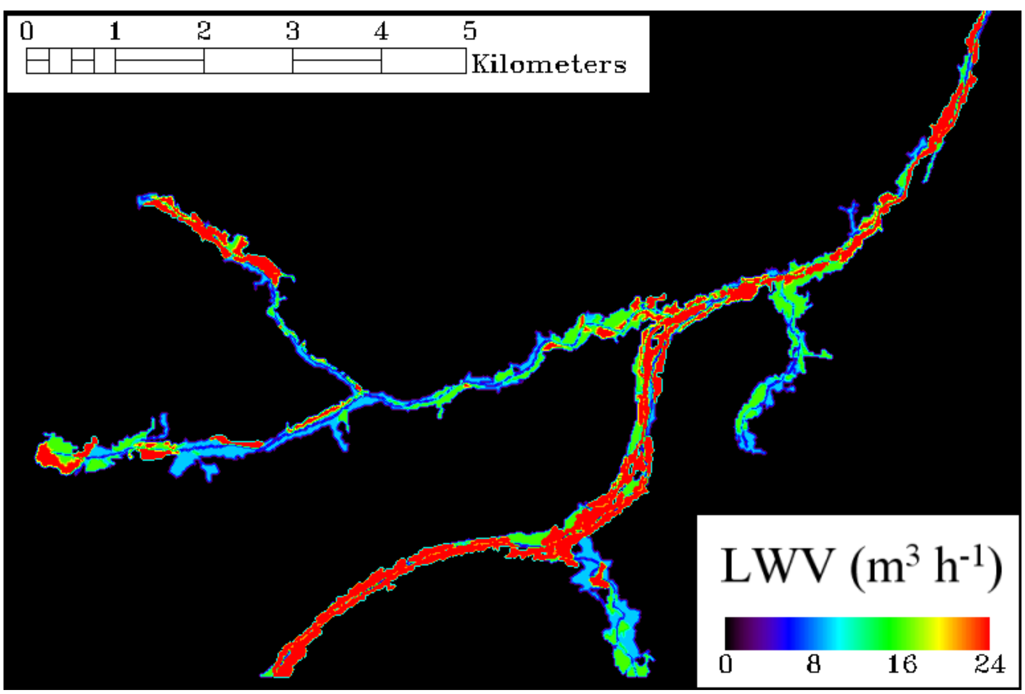

Figure 2. LWV results for a small section of the study area. The stream entering the image in the bottom left is a 6th order stream

The streams shown in Figure 2 range from 1st order to 6th order streams (Strahler stream order, with a 5km^2 criteria used for channel initiation). The values on the colour ramp refer to the LWV in m^3 ha^{-1}. The patterns of LWV shown in Figure 2 are a result of the relationship between vegetation type and stream order. The most common structural classes, woodland and open woodland were found next to all stream orders (these vegetation classes represent low – moderate loads of LWD and are represented by cyan and green colours in Figure 2), whereas the closed forest and open forest classes were predominant adjacent to the adjacent to 6th order stream (these vegetation classes generate high loads of LWD and are represented by orange and red colours in Figure 2).

The volume of standing timber (*wood*$_H$) predicted by the classification was compared with the volume of standing timber (*wood*$_H$) observed at the evaluation sites. The results of this comparison are shown in Figure 3.

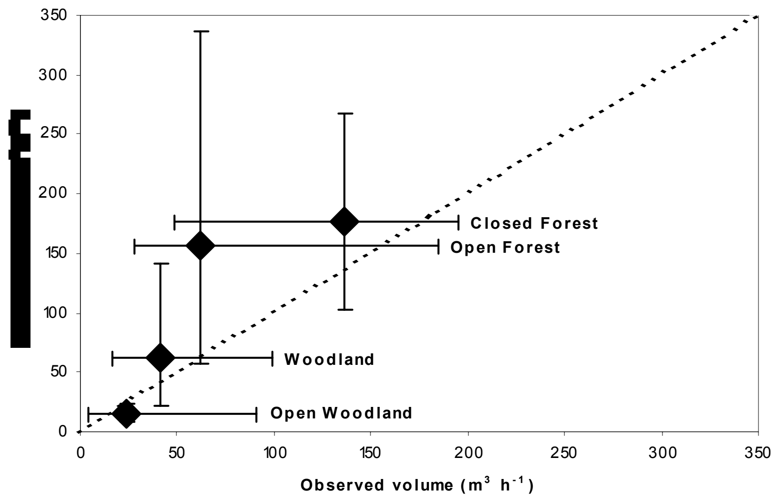

Figure 3. Predicted versus observed values of the volume of standing timber per hectare, the bars represent the 25th and 75th percentiles of the data.

The classification is overpredicting the amount of standing timber for three of the four classes. This is not of great concern, because the objective of this approach is to prioritise areas of riparian vegetation for protection/restoration, and to approximate the amount of LWD in the channel. It is not the aim of this study to predict the amount of LWD at a certain point in the channel network to the nearest cubic metre. Figure 4 shows the range of LWV within the channel predicted for each stream order in the study area.

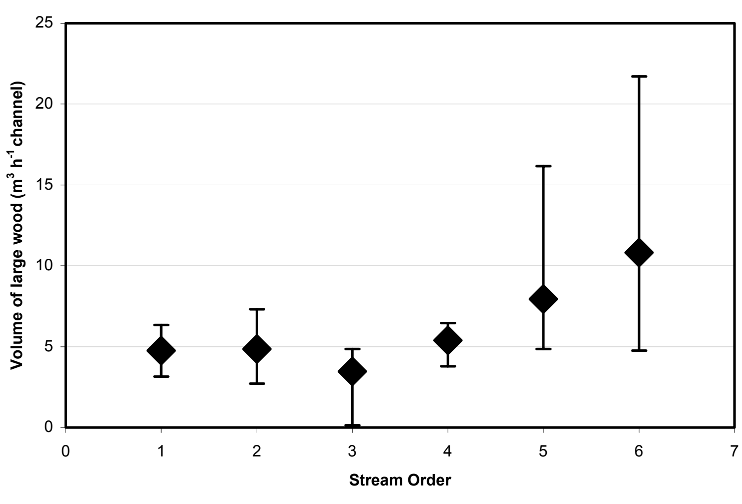

Figure 4. The range of LWV predicted for streams in the study area, the bars represent the 25th and 75th percentiles of the data.

DISCUSSION

The range of LWV predicted for streams in the study area (Figure 4) is consistent with volumes observed in other riparian studies including (Diez *et al*., 2001) and (Gurnell *et al*., 2002). It is interesting to note that both of these studies also observe very large variations in the volume of LWD for any given stream order.

The distribution of LWD according to stream order observed in this study differs from that observed by(Diez *et al*., 2001), in Spain and Pacific Northwest forests (Gurnell *et al*., 2002). The key difference being that LWD tends to increase downstream rather than decrease. This reflects a fundamental difference in the land use practices and climatic conditions between this study area and the other study areas. In this study area riparian vegetation along some 1st and 2nd order streams was cleared for grazing. In contrast the 1st and 2nd order streams in Pacific Northwest and the Iberian peninsula are often surrounded by high relief watersheds and remain partially or fully forested headwater streams. The distribution of riparian vegetation within the study area is strongly controlled by water availability, so that, even pre-clearing, many of the 1st, 2nd and 3rd order streams would only have supported open woodland or woodland, and open forest would predominantly exist along 4th, 5th and 6th order streams with small pockets of closed forest found along 5th and 6th order streams. The higher order streams within the study area have significant portions of remnant vegetation along the banks, and it is these portions of vegetation, particularly the open forest and closed forest that are predicted to be producing the large amounts of LWD as shown in Figure 2.

The information generated by this approach can be used to support decisions concerning the spatial prioritisation of riparian conservation and rehabilitation projects, despite the fact that the classification is overestimating the amount of standing timber. The imagery shown in Figure 2 identifies areas along high order streams where closed forest and open forest are providing large amounts of LWD to the stream. Such areas would be of high priority for conservation as part of a management strategy aimed at maintaining LWD loads within streams. The approach also identifies other areas along these streams where woodland and open woodland are providing smaller amounts of LWD to the stream. These areas would be of lower priority as part of management strategy aimed at maintaining LWD loads. The approach also identifies areas where no woody riparian vegetation is adjacent to the channel. Such areas could be visited and assessed as possible locations for LWD replacement depending on the local conditions. The results shown in Figure 4 could be used to guide a management strategy, the amount of LWD available for recruitment into 3rd order streams is lower than other stream orders, with 25% of 3rd order streams having zero woody vegetation adjacent to the channel. Such areas would be potential sites for either artificial placement of LWD if existing LWD levels were low, or they could be potential sites for riparian planting if maintaining long term supplies of LWD were a higher priority.

Previous attempts to describe the spatial distribution of LWD have included the use of airborne remote sensing to identify pieces of LWD within a channel network (Marcus *et al*., 2003) the success of this approach is hampered by the similarity in colour (and therefore reflectance) between LWD and other objects in the stream network. Another approach is the mechanistic model, such as RAIS (Welty *et al*., 2002). Such models seem useful for the areas in which they are developed, but can require a wide range of input data that can be difficult to obtain for large areas.

The advantage of the approach described in this study is that, with a limited amount of field work, and some inexpensive satellite imagery, it is possible to estimate the amount of LWD being generated by riparian vegetation anywhere within large (>100 000 ha) wateresheds. Another advantage of this approach is that uncertainty can be calculated at each step. The high level of variability in the volume of standing timber for each vegetation structural class, and the limited confusion between woodland and open woodland means that the uncertainty in the amount of LWD generated by any specific stand of riparian vegetation would be high. However at the stream link scale it is highly likely that a stream link surrounded by open forest will have more LWD inputs than a stream link surrounded by open woodland.

One of the disadvantages of this approach is that it doesn't provide information about the actual location or amount of LWD debris. If the results of this model were combined with a LWD transport model, then this shortcoming could be addressed. Another disadvantage is the cost of image processing software required to process satellite imagery. However this is a one-off cost, and may not be a factor for most watershed management agencies.

The approach described in this study could be readily applied to other areas provided the satellite imagery was available to generate the classification. Information about the relationship between vegetation structural classes and the volume of standing timber must be collected for each structural class observed in the study area. This can be done either via fieldwork or by referring to existing data where available.

CONCLUSIONS

A new approach for estimating the amount of LWD generated by riparian vegetation at a whole-of-watershed scale has been developed. The approach is reasonably successful at predicting the amount of standing timber for four vegetation structural classes. The volumes of terrestrial and aquatic LWD predicted are consistent with other studies into LWD production. The spatial information generated by this approach will be useful in prioritizing management strategies aimed at maintaining the amount of LWD in river systems.

ACKNOWLEDGMENTS

I would like to acknowledge the Cooperative Research Centre for Catchment Hydrology for providing my scholarship, I would also like to thank Sue Cuddy and AWRA reviewer for their comments and feedback in reviewing this paper.

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