Assessing the distribution and changes of instream woody habitat in south-eastern Australian rivers

Zeb Tonkin^{1*}, Adrian Kitchingman¹, Renae M. Ayres¹, Jarod Lyon¹, Ian D. Rutherford², Justin C. Stout², Paul Wilson³

¹Arthur Rylah Institute for Environmental Research. Department of Environment, Land, Water and Planning, Heidelberg, Victoria, 3084, Australia.

²The University of Melbourne. School of Geography, Parkville, Victoria, 3010, Australia.

³Water and Catchments. Department of Environment, Land, Water and Planning, East Melbourne, Victoria, 3002, Australia.

*Corresponding author:

Zeb Tonkin

Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, 123 Brown Street, Heidelberg, Victoria, 3084, Australia

Email: zeb.tonkin@delwp.vic.gov.au

Telephone: +61394508660

Fax: +61394508799

Short title: Assessing instream woody habitat distribution and change

This is the author manuscript accepted for publication and has undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: [10.1002/rra.3002](https://doi.org/10.1002/rra.3002)

Keywords: Large woody debris; Restoration; Management; Desnagging; Reference reaches; Condition; Riverscape

Author Manuscript

Abstract

Managers and communities are now artificially reintroducing instream woody habitat (IWH) to rivers following historic large scale removal. Riverscape scale datasets that quantify existing habitat conditions are fundamental to setting the priorities and allocating resources for such programs. Unfortunately, such datasets are rare, primarily because existing assessment approaches are limited in their accuracy (remote sensing) or are costly and labour intensive (field assessments). This study used both field assessments and aerial data to improve the accuracy of remotely sensed measures of IWH and estimate current IWH volumes and subsequent condition (compared to reference levels) across approximately 28,000 km of stream in the south eastern Australian state of Victoria.

We found that aerial measures, when used in conjunction with measures of stream size and riparian overhang, produced significantly better estimates of IWH loads than using aerial data alone. The state-wide assessment indicated streams currently have IWH volumes, on average, 41% lower than reference levels which represented an average reduction of $0.0207 \text{ m}^3 \text{ m}^{-2}$. The degree of IWH condition was highly variable across regions (20% – 95% reductions from reference levels); a likely reflection of regional variation in land use practices and past river works activities.

This scale of IWH reduction may pose major negative impacts on the ecological integrity of these streams. Whilst the approach used during this study has temporal and spatial limitations, it was designed as a generalised, rapid and relatively

inexpensive method to measure stream condition and assist with priority setting at state and regional levels.

Author Manuscript

Introduction

The presence of in-stream wood directly influences the geomorphology and ecology of a river through the interactions of wood with flow and sediment. Of particular importance to the aquatic assemblages found in most rivers is the role of instream wood in the provision of habitat. Instream wood influences local and reach scale hydraulics, and can assist in the development and diversity of channel habitat units such as pools and riffles, secondary channels, and changes in bed sediment grain size (Mosley, 1981; Gippel *et al.*, 1996; Rosenfeld and Huato, 2003; Borg *et al.*, 2007; Mao *et al.*, 2008; Eaton *et al.*, 2012). These geomorphic consequences, along with the in-stream wood itself, influence primary production and community composition, particularly by providing essential physical habitat for biofilms, invertebrates and fish (Benke *et al.*, 1985; Wallace *et al.*, 1995; Crook and Robertson, 1999; Brooks *et al.*, 2004; Nicol *et al.*, 2004; Gurnell *et al.*, 2005). As such, we refer to instream wood as instream woody habitat (IWH) to convey its ecological importance and need for its preservation, rather than use terms such as “woody debris” which can have negative connotations (e.g. Koehn *et al.*, 2004; Kitchingman *et al.*, 2013).

Traditional perceptions of the negative consequences of instream wood on flooding, navigation and erosion, led to extensive riparian clearing and direct removal of large quantities of IWH in rivers internationally (Abbe and Montgomery, 1996; Gippel *et al.*, 1996; Brooks *et al.*, 2004; Chin *et al.*, 2014). Such reductions in IWH have contributed to declines in the productivity and diversity of aquatic ecosystems (Crook and Robertson, 1999; Maddock, 1999; Brooks *et al.*, 2004). Importantly, research

demonstrating the positive role of IWH has led to an upsurge in IWH restoration, indirectly through the revegetation of riparian zones (to provide longer term wood inputs) and directly via wood reintroduction. The goal is to simulate natural conditions, encourage natural geomorphic processes, and reverse measured declines in diversity and abundance of aquatic organisms (Borg *et al.*, 2007; Máčka *et al.*, 2011). These activities have moved from small local projects, to consideration of wood at a riverscape scale (Ormerod, 2004; Gilvear *et al.*, 2012). There is therefore a need to understand the (dis)connectivity of river systems and associated IWH patterns across riverscapes (Fryirs and Brierly, 2007; Baillie *et al.*, 2008). A key element of achieving such an understanding is the collection and interpretation of reliable landscape-scale habitat data, which are fundamental to the setting of priorities and the allocation of resources by state and regional managers (Ladson *et al.*, 1999; Kaeser and Litts, 2012). Marcus and Fonstad (2008) illustrate that at the riverscape scale, our understanding of river form, process and function is largely based on locally intensive mapping of river reaches, or on spatially extensive, but low density, data scattered throughout a riverscape. Indeed, this is true for IWH, with few examples of assessments conducted over a range of stream sizes and across large catchments using consistent sampling methods (Baillie *et al.*, 2008). This is primarily because the most common methods for describing IWH, based on detailed measures such as volume, are difficult and costly to apply over large spatial scales (Marcus *et al.*, 2002; Kaeser and Litts, 2012; Atha and Dietrich, 2015).

Recent advances in optical remote sensing of rivers make it easier to generate accurate and continuous maps of in-stream attributes, including IWH, at sub-meter resolutions across entire watersheds (Marcus and Fonstad, 2008). Unfortunately, the quality of IWH data generated from aerial imagery is constrained by stream overhang, shading from riparian vegetation, and water clarity (e.g. Marcus *et al.*, 2002; Marcus and Fonstad, 2008). Alternatively (or complementarily), Kitchingman *et al.*, (2013) presented a new assessment procedure which incorporates a rapid on ground field survey method to map IWH densities. Their approach has since been applied to predict pre-disturbance (reference) IWH conditions across riverscapes (Kitchingman *et al.*, 2015), and to identify IWH units (no. pieces, complexity and volume) as part of an increasing government investment into assessing waterway health across the south-eastern Australian state of Victoria (Wilson, 2013).

This study builds on earlier work by Kitchingman *et al.*, (2015) that used field measures of IWH loads in reference reaches to develop a statistical model that could estimate the reference wood load for all major streams in the state of Victoria, south-eastern Australia (28,000 km of stream). We compare the reference IWH loads from Kitchingman *et al.*, (2015) with the existing IWH loads in this same stream network to make an assessment of the present IWH condition. This is, to our knowledge, the most spatially extensive mapping exercise of IWH (globally) to date.

Our study has two main components. Firstly, we determined existing IWH loads using aerial photographs. We accounted for the likely underestimate of IWH using

aerial derived IWH data (due to IWH hidden under overhanging vegetation and submerged under turbid water) by undertaking a series of on-ground IWH assessments to compare and calibrate measures derived from aerial photography alone. This calibration was applied to the census derived from the full aerial photograph set for the state (Wilson, 2013). Secondly, we compared our estimates of existing IWH loads with predictions of reference IWH volumes reported by Kitchingman et al., (2015) to assess the current condition of IWH across the stream network. We hypothesised that current volumes of IWH would be considerably lower than predictions of reference conditions, and that such reductions would vary across regions.

METHODS

Study area

The state of Victoria, located in south eastern Australia, covers approximately 227,600 km², encompassing watercourses exhibiting considerable variation in the geomorphology, hydrology and subsequent flora and fauna (VRHS, 2002; Kitchingman *et al.*, 2015). Victoria has been divided into 19 distinct 'Riverine Biological Regions' according to characteristics which influence or are the product of riverine aquatic habitats (VRHS, 2002). Approximately 1,500 'reaches' across 28,000 km of Victoria's Index of Stream Condition (ISC) network provided a broad framework to compare and assess various values and uses of rivers (Ladson *et al.*, 1999). For the purposes of this study, ISC reaches have been further divided into 38,988 stream 'links' (mean length 754 m), which form a fine-scale stream network, populated with a suite of physiographic, bioclimatic, edaphic and land-cover variables (see Chee and Elith, 2012).

Aerial derived IWH data

We used geo-referenced aerial photography (15 cm GSD +/- 3 pixels accuracy) and light detection and ranging (LIDAR) data of the entire Victorian ISC network undertaken during summer low flow periods during 2009, 2010 or 2011 (dependant on site specific hydrology). This full coverage of the ISC network has been used for a variety of catchment management reporting including measures of riparian health, bank condition and IWH (Wilson, 2013).

We used the statewide dataset of aerial photography derived IWH masses to create estimates of standardised wood volumes (m^3m^{-2}) for each of the stream links of the Victorian ISC network. The data set comprised of geolocated IWH masses, including their corresponding measures of size (footprint area (m^2)) and complexity (number of contiguous pieces / large branches) (Figure 2). This enabled direct comparisons with on-ground assessments undertaken in this and recent studies (Kitchingman *et al.*, 2013). We estimated overhanging vegetation cover (%) for each stream link using the LIDAR data set of the ISC network.

On-ground IWH assessments

On-ground IWH assessments were used to scrutinize the precision of data obtained from aerial photography. On-ground assessments included those conducted as part of the state-wide investigation of reference IWH distributions from 186 stream links (combined 83 km in length; see Kitchingman *et al.*, 2015) along with IWH assessments of a further 391 stream links (combined 305 km in length) of varying stream sizes, altitudes and riparian condition across the state. This resulted in the collation of high accuracy IWH data from a total of 477 stream links within the Victorian ISC stream network.

On-ground IWH assessments of stream links were undertaken between December 2011 - October 2012 during periods of stable low flows which were similar to the conditions of aerial imagery capture. Assessments were conducted following methods described in Kitchingman *et al.* (2013; 2015). Briefly, IWH were defined as parts of

dead trees, shrubs or masses thereof, with a minimum diameter of 0.1 m and length of 1 m, that were continually exposed to the operation of hydrogeomorphological processes (Gippel, Finlayson and O'Neill, 1996; Máčka, et al., 2011). The location of each IWH mass, along with its estimated size and complexity were recorded using a Trimble® GeoExplorer® XT6000 series handheld Global Navigation Satellite System coupled with a laser range finder. A Hummingbird® 998c SI side imaging sonar system was employed at boat sites to help identify submerged IWH. Both size and complexity parameters were categorised into one of four categories, producing 16 possible combinations of size and complexity for any given IWH mass.

Analysis

Raw data was processed using ESRI® ArcMap™ 10.0 GIS software. The aerial and on-ground assessment datasets were filtered to only include IWH masses within the toe-of-bank line, given this is the area most exposed to hydrogeomorphological processes and subsequent provision of habitat to aquatic fauna. Individual IWH masses within both datasets were then assigned into one of 16 categories (based on size-complexity scores) and corresponding volume estimates as presented by Kitchingman *et al.*, (2015; Table 1). The total IWH volume calculations for each stream link were then divided by the links toe-of bank area (most representative of the wetted surface area) to produce a standardised wood volume ($\text{m}^3 \text{m}^{-2}$), which is comparable to units reported in international literature (Hooke, 2007; Pesonen *et al.*, 2008) and recommended by Wohl *et al.*, (2010). Both sets of standardised wood volume estimates (generated from field-tested and aerial data sets respectively) were

then used to calibrate the aerial census data, and then to estimate IWH wood loads across the state.

I. Calibrating aerial IWH data

On-ground estimates of IWH volumes were used to assess the accuracy of aerially derived data. A generalized linear modelling (GLM) approach (using a gaussian distribution and logarithmic link function) was used to determine whether aerial data and measures of riparian overhang (% overhang) and stream size (mean bankwidth) generate more accurate estimates of IWH volumes than aerial estimates alone. The relative support for each of these models was assessed by calculating Akaike's Information Criterion (AIC), corrected for small sample size (AICc) (Burnham and Anderson, 1998). AICc values were rescaled as differences between that model and the model with the lowest AICc value. A prediction error was calculated using a K-fold cross validation with adjustment against bias (R cross-validation for Generalized Linear Models; R Development Core Team, 2013). To test the model's relevance the same approach was performed using only the aerial data as a predictor. We generated R^2 values of the two models to gauge any scale of improvement. The resulting best fitting model was then used to predict current IWH volumes for each of the 38,988 stream links.

II. Assessing current IWH loads across Victoria

To assess the current IWH load for individual stream links, current volumes were compared to the predicted reference values as reported by Kitchingman *et al.*, (2015)

using a paired t-test. A standardised condition value for each stream link, reported as the proportional change in IWH was produced by dividing the current IWH volume by its reference volume. A Kruskal-Wallis test was applied to identify whether there were differences in IWH condition values across the 19 river regions of Victoria (VRHS, 2002).

RESULTS

I. Calibrating aerial IWH data

Aerially derived estimates of IWH volumes were generally below the volumes generated by on-ground assessments. Volumes were increased North eastingly underestimated as the proportion of stream link area covered by vegetation overhang increased (Figure 3). Accordingly, the estimates of IWH volumes were tested using all interactions of aerial IWH volumes, vegetation overhang and bank width, with the best fitting model (model 1) having all main effects and aerial IWH volume two way interactions (Table 2). Using a 10 fold GLM cross-validation, the model prediction error was $0.00202 \text{ m}^3 \text{ m}^{-2}$ with a percentage error of 2.4%. The final model, model 1 explained 42% of the variance (adjusted R^2) compared to 15% when only aerial IWH volumes were used.

II. State-wide assessment of current IWH volumes

Model 1 was used to estimate current volumes of IWH for each of the 38,988 stream links of the Victoria's ISC network (Figure 4). The average current volume of IWH throughout Victorian rivers was predicted to be $0.0128 \text{ m}^3 \text{ m}^{-2}$ with average volumes varying both within and across river regions (Figure 4; Table 3).

Comparisons between predicted current and reference IWH volumes (as presented by Kitchingman *et al.*, 2015) indicated major reductions in IWH across Victoria (Figure 5; Table 3). Current IWH volumes were substantially lower than reference loads,

being on average $0.0207 \text{ m}^3\text{m}^{-2}$ below the state-wide average predicted level of $0.0336 \text{ m}^3\text{m}^{-2}$ ($t = 170.16$, $df = 38,931$, $p < 0.001$).

Condition values (which is defined as % change from reference predictions) represented an average reduction in IWH of approximately 41 % (Table 3). All river regions displayed a median negative condition value, indicating all regions were below predicted reference IWH levels. There was a significant difference in condition values across regions (Kruskal-Wallis, $p < 0.001$), with a general trend of river regions in western Victoria being in poorer IWH condition (higher % change) than more eastern river regions (Figure 5; Table 3). The South west floodplains, the Glenelg and South Central river regions, displayed the greatest percentage change and were predicted to be in poorest IWH condition (median reductions of 95%, 86% and 80% respectively). In comparison, the North east uplands, East Gippsland uplands and Alps were predicted to be in the best condition because they showed the smallest percentage change (20%, 23% and 37% reductions respectively). Indeed, our results follow a general trend of IWH condition being greatest in headwater streams (usually found within state- and national parks).

DISCUSSION

This study presented a consistent approach to measuring instream woody habitat volumes across catchments. Predictions of current IWH volumes, and comparisons with reference levels (as predicted by Kitchingman *et al.*, 2015), provide a quantitative assessment of the current condition of IWH across a large spatial scale. There are few examples of IWH assessments conducted across riverscapes (Baillie *et al.*, 2008; Atha and Dietrich, 2015), despite the global recognition of the importance of instream wood in shaping river health and subsequent upsurge in restoration programs (Borg *et al.*, 2007; Máčka *et al.*, 2011).

Our study revealed that IWH volumes across Victoria are on average 41% lower than reference levels. This represented an average reduction of $0.0207 \text{ m}^3 \text{ m}^{-2}$ in IWH.

Whilst it is well established that large expanses of Australian rivers and streams have reduced levels of IWH (Gippel *et al.*, 1996; Erskine and Webb, 2003; Brooks *et al.*, 2004), there has been little information available which quantifies such reductions to help guide wood reintroduction programs (e.g. Nicol *et al.*, 2004). The results of our study estimate the volumes of IWH needed to restore to near-reference conditions.

Of course, targets of IWH restoration, whether it be through direct IWH reintroductions or natural processes following riparian revegetation, will also be dependent on resource availability, ecological objectives and other constraints related to infrastructure risk and flooding.

We also found spatial differences in IWH condition across Victoria's riverine biological regions. For example, IWH volumes in the South west floodplain region were found to be 95% below reference condition, as compared to the North East uplands region which displayed median reductions of 20%. The varying condition of IWH across river regions primarily reflects varying land use practices and past river works activities, such as wood removal and bank stabilisation, as indicated by historical works records (DOWR, 1989). Within region variation in IWH condition in south eastern Australia has been demonstrated by Brooks *et al.*, (2003). They found that differences in IWH volumes and the geomorphology between two rivers in the East Gippsland region resulted from varying levels of wood removal and riparian clearing.

It is interesting to note that formal government sponsored wood removal has not been widespread in western Victoria (DOWR, 1989), so the low present IWH load in these western streams requires explanation. We propose that these numbers could be explained by informal removal of wood from streams by adjacent landholders; and by low levels of IWH recruitment back into the stream because of extensive removal of riparian vegetation, and the slower rate at which wood enters the stream in this region. The ISC data indicate the streams throughout western Victoria have lost much more of their riparian vegetation than in other regions of the state (Wilson, 2013), indicative of a reduction in the amount of IWH available to recruit back into the system. In addition, regional specific climatic and geomorphic processes that affect the rate of IWH recruitment, such as bank erosion rates and stream power, are also likely to

contribute to the regional variability of IWH condition (Nicol *et al.*, 2002; Benda and Sias, 2003). Indeed, western Victorian streams are also likely to exhibit low recruitment rates of IWH due to the low stream power and erosion rates (as interpreted by low rainfall and stream gradients) in the region.

The large scale of reductions in IWH loads documented in this study suggests that IWH loss is likely to have had major negative impacts on the ecological health of south eastern Australian streams. IWH plays a vital role in shaping the ecology of many streams as demonstrated by direct links between biofilms, invertebrates and fish (Benke *et al.*, 1985; Wallace *et al.*, 1995; Brooks *et al.*, 2004; Gurnell *et al.*, 2005). For example, fish communities within the Murray-Darling Basin, Australia, have been estimated to represent approximately 10 per cent of pre-European levels, with habitat degradation thought to be a major contributing factor (Lintermans, 2007). Current conditions of IWH are likely to continue to impact remaining ecological communities, particularly when also exposed to climate change threats of increased severity and frequency of drought across south eastern Australia (Balcome *et al.*, 2011; Morrongiello *et al.*, 2011). Several studies have demonstrated that rivers exposed to IWH and riparian removal, shift to a more homogenised bed profile, thus reducing the frequency and depth of pools (Wallace *et al.*, 1995; Brooks *et al.*, 2003). Pool habitats provide vital refugia for aquatic fauna during periods of low flow (Hermoso *et al.*, 2013). Therefore streams which have undergone major reductions in IWH, are also likely to be less resilient to any increases in environmental extremities, such as drought. Of course, testing the ecological consequences of changes in IWH

distribution is still required. Our results therefore provide opportunity to further investigate links between IWH distribution, condition and ecological indices (e.g. fish occupancy).

As predicted, stream reaches with greater proportions of riparian overhang increased the errors associated with aerial measures of IWH, which is recognised as a major limiting factor of aerial data sets (Marcus *et al.*, 2002; Marcus and Fonstad, 2008).

The modelling approach applied in this study greatly improved the accuracy of aerial IWH measures ($R^2 = 0.42$ compared to 0.15) by incorporating values of riparian overhang and stream size. Whilst the final predictions of IWH volumes are not without error (as are all model predictions), such errors may be viewed as negligible if used to identify stream reaches in poor condition, given reaches with low riparian overhang (<75%) have greater model accuracy and more likely to be in poorer condition (due to low IWH recruitment). Furthermore, the aerial, remote sensing approach overcomes costly and labour intensive on ground surveys, particularly if applied over broad spatial scales (see Marcus *et al.*, 2002; Kaeser and Litts, 2012; Atha and Dietrich, 2015).

We also acknowledge the uncertainties of this study beyond measurement error which should be considered during interpretation. Most notably, our assessment of condition, using observed / expected data, is largely governed by the reference wood load predictions of Kitchingman *et al.*, (2015). Whilst the authors of this study have outlined a variety of limitations which should be considered when interpreting these

estimates, it is important to highlight that any variation in estimated volumes of IWH under reference condition will change any associated condition score. For example, Kitchingman *et al.*, (2015) suggests predictions of pre-European IWH loads in ephemeral stream reaches may be over-estimated due to higher rates of wood decomposition. This effect may explain some of the large modelled decline in wood loads in the west of the state as these streams have proportionally more ephemeral streams (Robson, 2008).

Care should also be taken when interpreting predictions of IWH loads of reaches with variables outside of those used to generate the predictive models. For example, we surveyed very few river reaches greater than 80 m in width or subject to tidal influences, thus predictions for such reaches should be treated with caution. Given the assessment is lacking any temporal repetition, the results may quickly become redundant for reaches with high rates of IWH recruitment and movement (such as those with high stream power; e.g. Atha and Dietrich, 2015) or those which have experienced events known to influence IWH loads such as bushfire, flooding and severe storms (Young, 1994; Daniels, 2006). River reaches with high stream power and / or healthy riparian zones, however, are generally not targeted for restoration works, thus, temporal variation in data will be of less concern if used to inform further investment such as wood reintroduction.

Kitchingman *et al.*, (2013) designed this IWH assessment approach as a generalised method to support broad scale management decisions. Whilst this approach is suitable

to broadly identify areas for IWH restoration, we recommend that further investment at smaller spatial scales is needed to provide detailed site based information. For example, if a reach is in poor condition and requires restoration, it should undergo a more detailed on-ground assessment of IWH, with consideration of other factors which may influence management objectives including site access, ecological value, public support, funding, resources and likelihood of success of the intervention. Furthermore, during the prioritization process, a site specific assessment should be undertaken to determine the probability of reaches autonomously recovering a sufficient load of IWH. These assessments should be based on the physical processes that deliver and remove wood from that reach, and if an adequate source of wood is available for recruitment.

The ability to assess IWH volumes and subsequent condition across riverscapes, as presented in this study, enables waterway managers to report on stream condition, assist with priority setting, judge the long-term effectiveness of rehabilitation programs and assist with adaptive management at state and regional levels (Ladson *et al.*, 1999; Kaeser and Litts, 2012). We demonstrated that south eastern Australian streams have undergone dramatic reductions in IWH, which is likely to subsequently effect the ecological integrity of these waterways. Our findings endorse the already large investments in stream restoration programs and provide an opportunity to test the ecological consequences of changes in IWH distribution.

Acknowledgements

We thank the many people who contributed to this project. In particular, Justin O'Mahony, Joanne Kearns, Graeme Hackett, Scott Raymond, Jason Lieschke and Mike Nicol assisted in the collection of field data; Paul Maloney and Nick Bond for biometric support; and Matt Bruce for his helpful review of the manuscript. This work was funded by the Natural Resources and Water Sector groups of the Department of Environment and Primary Industries, Victoria.

Author Manuscript

References

- Abbe TB, Montgomery DR. 1996. Large woody debris jams, channel hydraulics and habitat formation in large rivers. *Regulated Rivers: Research & Management* **12**: 201-221.
- Atha JB, Dietrich JT. 2015. Detecting Fluvial Wood in Forested Watersheds using LiDAR Data: A Methodological Assessment. *River Research and Applications*: Early view DOI 10.1002/rra.2989.
- Baillie BR, Garrett LG, Evanson AW. 2008. Spatial distribution and influence of large woody debris in an old-growth forest river system, New Zealand. *Forest Ecology and Management* **256**: 8.
- Balcombe SR, Sheldon F, Capon SJ, Bond NR, Hadwen WL, Marsh N, Bernays SJ. 2011. Climate-change threats to native fish in degraded rivers and floodplains of the Murray–Darling Basin, Australia. *Marine and Freshwater Research* **62**: 1099–1114.
- Benda LE, Sias JC. 2003. A quantitative framework for evaluating the mass balance of in-stream organic debris. *Forest Ecology and Management* **172**(1): 1-16.
- Benke AC, Henry RL, Gillespie DM, Hunter RJ. 1985. Importance of Snag Habitat for Animal Production in Southeastern Streams. *Fisheries* **10**: 8-13.

Borg D, Rutherford I, Stewardson M. 2007. The geomorphic and ecological effectiveness of habitat rehabilitation works: Continuous measurement of scour and fill around large logs in sand-bed streams. *Geomorphology* **89**: 205-216.

Brooks AP, Brierley GJ, Millar RG. 2003. The long-term control of vegetation and woody debris on channel and flood-plain evolution: insights from a paired catchment study in southeastern Australia. *Geomorphology* **51**:7-29.

Brooks AP, Gehrke PC, Jansen JD, Abbe TB. 2004. Experimental reintroduction of woody debris on the Williams River, NSW: geomorphic and ecological responses. *River Research and Applications* **20**: 513-536.

Burnham KP, Anderson DR. 1998. *Model Selection and Inference: A Practical Information-Theoretic Approach*. Springer-Verlag: New York, NY, USA.

Chee YE, Elith J. 2012. Spatial data for modelling and management of freshwater ecosystems. *International Journal of Geographical Information Science* **26**: 2123-2140.

Chin A, Laurencio LR, Daniels MD, Wohl E, Urban MA, Boyer KL, Butt A, Piegay H, Gregory KJ. 2014. The significance of perceptions and feedbacks for effectively managing wood in rivers. *River Research and Applications* **30**: 98-111.

Crook DA, Robertson AI. 1999. Relationships between riverine fish and woody debris: implications for lowland rivers. *Marine and Freshwater Research* **50**: 941-953.

Daniels M. 2006. Distribution and dynamics of large woody debris and organic matter in a low-energy meandering stream. *Geomorphology* **77** (3): 286-298.

DOWR. 1989. *Water Victoria: an environmental handbook*. VGPO on behalf of the Department of Water Resources: Melbourne, Victoria, Australia.

Eaton BC, Hassan MA, Davidson SL. 2012. Modelling wood dynamics, jam formation, and sediment storage in a gravel-bed stream. *Journal of Geophysical Research: Earth Surface* **117**(F4). DOI:10.1029/2012JF002385.

Erskine WD , Webb AA. 2003. Desnagging to resnagging: new directions in river rehabilitation in southeastern Australia. *River Research and Applications* **19**: 233-249.

Fryirs KA, Brierly GJ. 2007. Buffers, barriers, and blankets: The (dis)connectivity of catchment-scale sediment cascades. *Catena* **70**(1): 45-67.

Gilvear DJ, Casas-Mulet R, Spray, CJ. 2012. Trends and issues in delivery of integrated catchment scale river restoration: Lessons learned from a national river restoration survey within Scotland. *River Research and Applications* **28**: 234-246.

Gippel CJ, Finlayson BL, O'Neill IC. 1996. Distribution and hydraulic significance of large woody debris in a lowland Australian river. *Hydrobiologia* **318**(3): 179-194.

Gurnell A, Tockner K, Edwards P, Petts, G. 2005. Effects of deposited wood on biocomplexity of river corridors. *Frontiers in Ecology and the Environment* **3**: 377-382.

Hermoso V, Ward DP, Kennard MJ. 2013. Prioritizing refugia for freshwater biodiversity conservation in highly seasonal ecosystems. *Diversity and Distributions* **19**: 1031–1042.

Hooke JM. 2007. Spatial variability, mechanisms and propagation of change in an active meandering river. *Geomorphology* **84**: 277-296.

Kaesler AJ, Litts TL. 2012. A novel technique for mapping habitat in navigable streams using low-cost side scan sonar. *Fisheries* **35**: 163-174.

Kitchingman A, Tonkin Z, Lyon J. 2013. A novel approach to spatially assessing instream woody habitat densities across large areas. *Journal of Environmental Management* **128**: 555–560.

Kitchingman A, Tonkin Z, Ayres RM, Lyon J, Stout JC, Rutherford ID, Wilson P. 2015. Predicting natural instream woody-habitat loads across large river networks. *Marine and Freshwater Research*: Online early DOI 10.1071/MF15246.

Ladson AR, White LJ, Doolan JA, Finlayson BL, Hart BT, Lake PS, Tilleard JW. 1999. Development and testing of an Index of Stream Condition for waterway management in Australia. *Freshwater Biology* **41**: 453-468.

Lintemans M. 2007. 'Fishes of the Murray-Darling Basin: an introductory guide.' (Murray-Darling Basin Commission: Canberra).

Máčka Z, Krejčí L, Loučková B, Peterková L. 2011. A critical review of field techniques employed in the survey of large woody debris in river corridors: a central European perspective. *Environmental Monitoring and Assessment* **181**: 291-316.

Maddock I. 1999. The importance of physical habitat assessment for evaluating river health. *Freshwater Biology* **41**: 373-391.

Mao L, Andreoli A, Comiti F, Lenzi MA. 2008. Geomorphic effects of large wood jams on a sub-antarctic mountain stream. *River Research and Applications* **24**: 249-266.

Marcus WA, Marston RA, Colvard Jr CR, Gray RD. 2002. Mapping the spatial and temporal distributions of woody debris in streams of the Greater Yellowstone Ecosystem, USA. *Geomorphology* **44**: 323-335.

Marcus WA, Fonstad MA. 2008. Optical remote mapping of rivers at sub-meter resolutions and watershed extents. *Earth Surface Processes and Landforms* **33**: 4-24.

Morrongiello J R, Crook DA, King AJ, Ramsey DSL, Brown P. 2011. Impacts of drought and predicted effects of climate change on fish growth in temperate Australian lakes. *Global Change Biology* **17**: 745–755.

Mosley MP. 1981. The influence of organic debris on channel morphology and bedload transport in a New Zealand forest stream. *Earth Surface Processes and Landforms* **6**(6): 571-579.

Nicol SJ, Lieschke JA, Lyon JP, Koehn JD. 2004. Observations on the distribution and abundance of carp and native fish, and their responses to a habitat restoration trial in the Murray River, Australia. *New Zealand Journal of Marine and Freshwater Research* **38**: 541-551.

Ormerod S. 2004. Editorial: A golden age of river restoration science. *Aquatic Conservation* **14**: 543-549.

Pesonen A, Maltamo M, Eerikäinen K, Packalèn P. 2008. Aerial laser scanning-based prediction of coarse woody debris volumes in a conservation area. *Forest Ecology and Management* **255**: 3288-3296.

R Development Core Team. 2013. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing: Vienna, Austria.. Retrieved from <http://www.R-project.org>

Robson, B. 2008. *Managing flows for ephemeral streams* (Fact sheet 2). Land and Water Australia, Australian Government: Canberra, Australia.

Rosenfeld JS, Huato L. 2003. Relationship between large woody debris characteristics and pool formation in small coastal British Columbia streams. *North American Journal of Fisheries Management* **23**: 928-938.

VRHS. 2002. *Healthy rivers, healthy communities and regional growth: Victorian River Health Strategy*. Department of Natural Resources and Environment: Victoria, Australia.

Wallace JB, Webster JR, Meyer JL. 1995. Influence of log additions on physical and biotic characteristics of a mountain stream. *Canadian Journal of Fisheries and Aquatic Sciences* **52**: 2120-2137.

Wilson, P. 2013. *Index of Stream Condition: The third benchmark of Victorian river condition*. Department of Environment and Primary Industries: East Melbourne, Victoria, Australia

Wohl E, Cenderelli DA, Dwire KA, Ryan-Burkett SE, Young MK, Fausch KD. 2010. Large in-stream wood studies: a call for common metrics. *Earth Surface Processes and Landforms* **35**: 618-625.

Young MK. 1994. Movement and characteristics of stream-borne coarse woody debris in adjacent burned and undisturbed watersheds in Wyoming. *Canadian Journal of Forest Research* **24**: 1933-1938.

Table 1. Footprint size (m²), complexity score and estimated volumes (m³) for each of the 16 Instream Woody Habitat (IWH) mass categories. Table reproduced from Kitchingman *et al.*, (2015).

IWH category	Footprint size (m ²)	Complexity category (no. stems)	Mean volume (m ³)
1_1	1 - 5	1	1.10
1_2	1 - 5	2	0.63
1_3	1 - 5	3	0.70
1_4	1 - 5	≥ 4	0.94
2_1	> 5 - 10	1	3.67
2_2	> 5 - 10	2	1.06
2_3	> 5 - 10	3	0.56
2_4	> 5 - 10	≥ 4	1.20
3_1	>10 - 20	1	8.12
3_2	>10 - 20	2	1.86
3_3	>10 - 20	3	1.53
3_4	>10 - 20	≥ 4	2.38
4_1	> 20	1	18.18
4_2	> 20	2	7.44
4_3	> 20	3	7.57
4_4	> 20	≥ 4	14.62

Author Manuscript

Table 2. Results of model selection procedure for 19 combinations of instream woody habitat (IWH) volume predictors. Predictors were aerial_vol = aerial standardised IWH volume ($\text{m}^3 \text{m}^{-2}$) for stream link; mean_bw = average toe-of-bank channel width for stream link; veg_over = proportion of stream link area covered by overhanging vegetation. AICc Akaike's Information Criterion corrected for small sample size; ΔAICc , difference in AICc between this model and the model with the lowest AICc.

Model No.	Model	Log_Likelyhood	AICc	ΔAICc
1	aerial_vol + mean_bw + veg_over + aerial_vol : mean_bw + aerial_vol : veg_over	6	942.625	0
2	aerial_vol + mean_bw + veg_over + aerial_vol : mean_bw + mean_bw : veg_over	6	942.1845	0.881114196
3	aerial_vol + mean_bw + aerial_vol : mean_bw + mean_bw : veg_over	5	940.8948	1.417735193
4	aerial_vol + mean_bw + veg_over + aerial_vol : mean_bw + aerial_vol : veg_over + mean_bw : veg_over	7	942.873	1.553957037
5	aerial_vol + mean_bw + veg_over + aerial_vol : mean_bw + aerial_vol : veg_over + aerial_vol : mean_bw : veg_over	7	942.7949	1.710296563
6	aerial_vol + mean_bw + veg_over + aerial_vol : mean_bw + aerial_vol : veg_over + mean_bw : veg_over + aerial_vol : mean_bw : veg_over	9	944.7445	1.933014413
7	aerial_vol + mean_bw + aerial_vol : mean_bw	4	939.3129	2.546022669
8	aerial_vol + mean_bw + veg_over + aerial : mean_bw	5	940.2606	2.686115539
9	aerial_vol + mean_bw + veg_over + aerial_vol : mean_bw + mean_bw : veg_over + aerial_vol : mean_bw : veg_over	7	942.2492	2.801580829
10	aerial_vol + mean_bw + veg_over + aerial_vol : mean_bw + aerial_vol : veg_over + mean_bw:veg_over + aerial_vol : mean_bw : veg_over	8	943.0264	3.304501198
11	aerial_vol + mean_bw + veg_over+aerial_vol : mean_bw + aerial_vol : mean_bw:veg_over	6	940.2794	4.691276226
12	aerial_vol + aerial_vol : mean_bw	3	886.974	105.1954903
13	aerial_vol + veg_over + aerial_vol : mean_bw	4	886.9817	107.2084326
14	aerial_vol + veg_over + aerial_vol : mean_bw + aerial_vol : mean_bw : veg_over	5	887.5852	108.036928
15	aerial_vol + mean_bw + veg_over	4	855.1607	170.8504286
16	aerial_vol + mean_bw + veg_over + aerial_vol : veg_over	5	855.4794	172.2485121
17	aerial_vol + mean_bw	3	830.5078	218.1277722
18	aerial_vol + veg_over	3	813.5829	251.9776655
19	aerial_vol	2	782.7344	311.6533704

Author Manuscript

Table 3. Instream woody habitat volumes (average $\pm$ se; $\text{m}^3 \text{m}^{-2}$) as predicted under reference (from Kitchingman *et al.*, 2015) and current conditions for each of Victoria's river regions. Average differences in volume and median percentage change values (condition value) between reference and current volumes also presented.

RIVER REGION	Reference volume	se	Current volume	se	Change	se	% change	se
Alps	0.0192	0.0002	0.0165	0.0005	-0.0027	0.0005	-36.5	2.7
East Gippsland east of the Snowy River - lowlands	0.0304	0.0005	0.0145	0.0003	-0.0159	0.0005	-51.6	2.0
East Gippsland east of the Snowy River - uplands	0.0223	0.0003	0.0159	0.0003	-0.0064	0.0004	-23.4	1.8
Glenelg catchment	0.0585	0.0002	0.0095	0.0003	-0.0490	0.0004	-85.9	0.4
Grampians	0.0661	0.0006	0.0235	0.0016	-0.0426	0.0017	-76.3	2.4
North central floodplains	0.0482	0.0004	0.0102	0.0002	-0.0380	0.0004	-79.9	0.4
North central midlands	0.0319	0.0003	0.0132	0.0002	-0.0187	0.0003	-61.2	1.1
North central uplands	0.0206	0.0002	0.0124	0.0003	-0.0082	0.0003	-46.0	1.9
North east floodplains	0.0173	0.0004	0.0118	0.0004	-0.0055	0.0005	-36.4	23.8
North east uplands	0.0141	0.0002	0.0113	0.0002	-0.0028	0.0002	-20.0	11.7
North west floodplains	0.0561	0.0002	0.0180	0.0004	-0.0381	0.0004	-72.1	0.6
North west uplands	0.0457	0.0003	0.0138	0.0002	-0.0319	0.0004	-72.5	0.7
Otway Ranges	0.0328	0.0005	0.0176	0.0004	-0.0152	0.0005	-46.4	1.3
South central	0.0456	0.0003	0.0112	0.0002	-0.0344	0.0004	-80.4	0.7
South central lowlands	0.0396	0.0004	0.0185	0.0005	-0.0211	0.0007	-55.0	1.5
South central uplands	0.0284	0.0003	0.0194	0.0003	-0.0090	0.0003	-30.7	1.1
South east floodplains	0.0322	0.0002	0.0115	0.0002	-0.0207	0.0003	-69.6	0.7
South east slopes	0.0171	0.0001	0.0089	0.0001	-0.0083	0.0001	-56.0	2.4
South west floodplains	0.0576	0.0003	0.0055	0.0002	-0.0522	0.0004	-95.1	0.3

Strezleckis	0.0242	0.0005	0.0139	0.0003	-0.0103	0.0006	-40.0	2.3
Wilsons Promontory	0.0350	0.0017	0.0166	0.0016	-0.0184	0.0025	-48.3	6.0
AVERAGE	0.0336	0.0001	0.0128	0.0001	-0.0207	0.0001	-41.0	1.0

Figure captions

Figure 1. The location of on-ground assessments of instream woody habitat (black x's) relative to the riverine biological regions (VRHS 2002) in Victoria, Australia. Numbers correspond to different riverine biological regions, as named in the insert box. Figure modified from Kitchingman et al., (2015) to include additional sites.

Figure 2. Example of an aerial image displaying identified instream woody habitat (IWH) masses on the Ovens River. Size (S) and complexity (C) scores included for several masses.

Figure 3. Scatterplot of raw differences (and Loess smoother line of fit) between measures of instream woody habitat volumes (m^3m^{-2}) between ground-truthed sites and aerial data for 477 stream links across Victoria. Values > 0 indicate underestimation of aerial measures.

Figure 4. Predicted current instream woody habitat volumes (average m^3m^{-2}) across 38,988 stream links of Victoria. Riverine biological region boundaries also included.

Figure 5. Predicted current condition of IWH as indicated by the % change from predicted reference levels (as reported in Kitchingman *et al.*, 2015) across 38,988 stream links of Victoria. Riverine biological regions and detailed insert highlight variation of IWH condition across and within regions and rivers.

Author Manuscript

rra_3002_f2

RRA_3002_F3.tif

rra_3002_f4

rra_3002_f5

Minerva Access is the Institutional Repository of The University of Melbourne

Author/s:

Tonkin, Z;Kitchingman, A;Ayres, RM;Lyon, J;Rutherford, ID;Stout, JC;Wilson, P

Title:

Assessing the Distribution and Changes of Instream Woody Habitat in South-Eastern Australian Rivers

Date:

2016-09-01

Citation:

Tonkin, Z., Kitchingman, A., Ayres, R. M., Lyon, J., Rutherford, I. D., Stout, J. C. & Wilson, P. (2016). Assessing the Distribution and Changes of Instream Woody Habitat in South-Eastern Australian Rivers. RIVER RESEARCH AND APPLICATIONS, 32 (7), pp.1576-1586. <https://doi.org/10.1002/rra.3002>.

Persistent Link:

<http://hdl.handle.net/11343/291001>