

Post Gold Rush Stream Regeneration: Implications for Managing Exotic and Native Vegetation

*Michael Wilson*¹

SUMMARY: Riparian vegetation type influenced organic matter and sediment dynamics in 1st to 3rd order streams centered on Daylesford, central Victoria. Sites had similar geologic, geomorphic, gold mining and land use histories. Native vegetation consisted of regeneration from post gold rush to present (150 years). Exotic tree species had colonised some streams over the last 50 years. Litter dynamics were similar in willow and native sites, and litter contributed 75% of the total organic matter input to the streams. Photosynthetic activity by aquatic plants and algae occurred under both deciduous and evergreen canopies, and contributed 15% of the total organic matter input to the streams. Groundwater from fresh and mineral springs maintained summer flows but directly contributed little organic matter (4 mg DOM/L). However, following a short (11m) flow path through riparian sediment, groundwater could become a significant source of organic matter (14 mg DOM/L). It was estimated that groundwater, following flow through riparian sediments, could contribute approximately 9% of the total organic matter input to the streams. Benthic organic matter storage in willow lined reaches was an order of magnitude greater than in reaches lined by native riparian communities. Similarly, sediment storage was three times greater. Of all aspects considered in this study it was this aggradation at willow sites that most clearly distinguished the native and willow sites. Nutrient and sediment mobilisation and disruption of biota are thus a probable outcome of willow removal along Spring Creek. This suggests that where riparian vegetation removal is being considered, caution should be applied. It seems illogical to remove riparian vegetation solely on the basis of taxonomy (i.e. native vs. exotic) where nutrient and sediment dynamics are important considerations. I suggest a management perspective that encompasses the ecosystem rather than simply the riparian vegetation's taxonomy is required.

THE MAIN POINTS OF THIS PAPER

- Stream reaches with willow or native riparian forests were distinguished by greater 'vigour' (as measured by GPP or community respiration) and sediment and organic matter storages at willow sites.
- Willow removal per kilometer of Spring Creek could release to the stream an estimated 287 tons of sediment, 30 tons of organic matter and 323 kilograms of phosphorous from the stream channel alone.
- Unforeseen consequences may thus occur if riparian vegetation is managed solely on the basis of taxonomy (i.e. willows are 'bad' and should be removed). Watersheds, including stream and river corridors, require a broader ecosystem approach to management.

1. INTRODUCTION

In the central Victorian goldfields stream channel ecosystems were greatly disturbed during the gold rush(es) of the 1850s. The nature of disturbance was many fold, including direct sluicing of sediments, redirection of the stream channel with stone walls and along water races, and temporary but very dense human settlements along the streams. The riparian and valley forests were a vital source of fuel and timber. Wombat, Spring and Sailors Creeks surrounding the towns of Daylesford and Hepburn in central Victoria, the study locality for this paper, were rich in alluvial gold and were heavily worked during the gold rushes.

Riparian and stream vegetation, completely removed during the gold rushes, has regenerated over the intervening one and a half centuries. In some streams the riparian forest is dominated by natives, in others a relatively recent phase of willow establishment has occurred. The spread of willows along Spring Creek appears to have followed cessation of grazing and frequent burning of the gully that occurred in the 1940's.

Through dendrochronology, Sniderman (1998) showed the willows in Spring Creek to be similarly aged (an estimated 75% of willows established over a period 30-45 years ago), with negligible recruitment for 20 years. Succession is occurring at these sites with willows being replaced by sycamore and European ash (Sniderman 1998).

Studies attempting to address management of willows in south east Australia have emphasised organism interactions (e.g.: invertebrates; Schulze and Walker 1997, Pidgeon and Cairns 1981, Beasley 1991, Read 1996: fish; Read 1996: microbial; Schulze and Walker 1997). The clear differences between deciduous, rapidly processed willow leaves and evergreen, more slowly processed eucalypt leaves (Schulze and Walker 1997) was one factor that led most of the above researchers to hypothesise that clear differences in biota would be observed. However, the above studies showed few observable differences in biotic richness within willow lined reaches and those lined with other, often native, riparian vegetation communities.

¹ Centre for Environmental Management, University of Ballarat, Ballarat, 3353.
Ph: (03) 5327 9104 Fax: (03) 5327 9240 Email: m.wilson@ballarat.edu.au

A focus on organism interactions or species richness alone does not necessarily indicate if an ecosystem is functioning well, i.e. if it is 'healthy'. In other words, the absence of notable biotic differences in willow and native lined aquatic environments does not, in itself, indicate an absence of notable differences in ecosystem processes between the two environments. However, Rapport et al (1998) suggest that organisation (assessed as the diversity and number of interactions between components), along with vigour and resilience are the three indicators of ecosystem health. Thus, organism interaction studies are shedding light on one aspect of ecosystem health.

Dickinson and Murphy (1998) suggest that all ecosystems are the product of interactions between an energy subsystem and a material cycling subsystem. Organic matter and sediments are key materials that transfer energy and nutrients between terrestrial (the 'catchment') and aquatic (the 'stream') environments. They are thus fundamental players in the energy and material cycling subsystems of stream corridor ecosystems. Similarly Fisher et al. (1998) state that consideration of those factors that influence the capacity of flowing water ecosystems to retain materials is at the heart of stream ecology.

In this paper I explore organic matter dynamics and sediment storages in willow lined and native lined streams in Central Victoria. In doing so I hope to explore 'vigour', an indicator of ecosystem health (Rapport et al. 1998), as well as aspects of the retention of these key materials in stream ecosystems.

2. METHODS

2.1 Study site description

Wombat, Sailors and Spring Creeks surround Daylesford and Hepburn (37°21'S 144°08'E) in central Victoria. The streams are low order, mid gradient streams (Table 1) with catchments that are predominately forested (Wombat State Forest), but with extensive agricultural and urban land use. Springs are a conspicuous contributor to stream flow.

Fringing vegetation type was classified into six types and was used to locate six experimental reaches each 100m in length. Three were dominated by mixed eucalypt and wattle riparian vegetation (Native sites), two with willow domination (Willow sites) and one site with an apparently even mix of natives and willows (Sailors Creek Mixed site).

2.2 Groundwater organic matter inputs

Mineral and fresh water springs as well as a bore within the dominant Ordovician bedrock aquifer (Shugg 1996), were sampled for dissolved organic matter between spring 1997 and spring 1998. Waters were filtered (0.45 µm) into combusted (500-550°C for a minimum of 2 hours) glass bottles and immediately acidified (pH < 2). Total non-purgable ('organic') carbon was determined by

the Water Studies Centre, Monash University. The ash free dry weight (AFDW) of organic matter was assumed to contain 50% carbon (Treadwell et al. 1997), thus dissolved organic carbon was multiplied by 2 to estimate dissolved organic matter as AFDW. Flow from each spring was measured.

2.3 Riparian groundwater transect

An opportunity to observe organic matter transformation across the riparian - stream boundary was provided by a fresh water spring that flowed as surface water down the outcropping bedrock of the valley side to the riparian zone. The spring water then ponded on the level riparian floodplain. The majority the percolated through the riparian sediments to Spring Creek. Willows dominated the riparian vegetation. Six shallow bores were augured to bedrock (max. depth 0.61 m), along a transect perpendicular to stream flow. Surface spring water (at 11m from the stream edge) and surface creek water (at 0 m) defined the transect. Saturated hydraulic conductivity (auger hole method, nomographs in Landon 1984), relative ground water depth, relative land surface height and dissolved organic matter content of bore and surface waters (as for groundwater DOC above) were determined in January 1998.

2.4 Direct litter inputs from fringing vegetation

Five horizontal litter traps (0.84 m²) were located at each experimental reach. Positions were randomly selected and traps were emptied at approximately two-monthly intervals between summer 1996/97 and winter 1998. Organic matter was air dried and weighed. Totals (unsorted litter) are presented in this paper. Dry weights were converted to ash free dry weights (AFDW) using conversions determined by Schulze and Walker (1997) for eucalypt leaves (AFDW=94.5% dry weight for native litter) and weeping willow leaves (AFDW=88% dry weight for willow litter). An average (91%) was used for mixed site litter.

2.5 In-stream photosynthesis and respiration (community metabolism).

Upstream - downstream diel dissolved oxygen curves (see Owens 1969) were used to determine community metabolic activity at Wombat Creek Native site and Spring Creek Willow site between spring 1997 and spring 1998. These sites, whilst not identical with respect to vegetation, were comparable in catchment size, had very similar geologic, geomorphologic and gold mining histories, and both were downstream of small water supply reservoirs (<400 ML).

Dissolved oxygen meters (TPS, LC82 with ED500 DO₂ probe) were connected to a datalogger (Campbell Scientific 21X) recording at 10 minute intervals for a minimum of 24 hours and up to 72 hours. Down loaded data was corrected for calibration drift and plotted against time. Downstream probe data was shifted by a time corresponding to reach retention time, i.e. the time taken for a hypothetical parcel of water to travel from the upstream probe to the downstream probe.

Calculations to determine gross primary production (GPP) and community respiration were based on equations in Owens (1969). Data can be converted from units of O₂ to units of ash free dry weight (AFDW) by assuming that 1g O₂ = 0.375 g C and using quotients of 1.2 for photosynthesis and 0.85 for respiration (Bott et al. 1985 quoted in Treadwell et. al. 1997) and, finally, by assuming AFDW is 50% C.

Autotrophic respiration rates were assumed to be 50% of GPP (Treadwell et al 1997 and others in Webster and Meyer 1997). Heterotrophic respiration was assumed to be community respiration minus autotrophic respiration.

A direct measure of diffusion was made. A sheet of plastic, either 10 m or 20 m long, was laid over the flowing stream with the edges of the plastic rising a short distance up the channel bank and held in place with stones. The upstream edge of the plastic was then buried in the stream sediment. By isolating the flow over the plastic from benthic and periphyton communities, respiration and photosynthesis no longer contributed to changes in dissolved oxygen. Diffusion was measured as the difference between the dissolved oxygen content of the stream water at the upstream and downstream edges of the plastic. This correlated well with estimates based on stream dimensions and velocity (equations in Owens 1969), and had the benefit of being able to be used during times of low stream flow.

2.6 Benthic organic matter storage

Quadrats of 0.1m² were sampled to a maximum of 10 cm depth from 5 random locations along the channel midline at each site in June 1997. Samples were dried at 105°C to constant weight, ashed at 500°C for 5 hours and reweighed. The ash free dry weight was used as a measure of organic matter content. Substrate (bedrock, cobble, pebble, sand, silt/mud or willow root mat), was recorded at one metre intervals along each 100m reach. Observations of depth to bedrock were made at all sample locations.

3. RESULTS AND DISCUSSION

3.1 Post gold rush recovery?

During the gold rush we can imagine that the streams were turbid with mobilised sediments from the digging and sluicing activities of thousands of alluvial miners. It is difficult to imagine stream autotrophs surviving such conditions. With little or no riparian vegetation and heavily cleared surrounding ridges, litter fall would presumably have been low. As a result, would organic matter inputs have been very low? Could the streams retain materials without vegetation to stabilise banks and continual disturbance by miners? Without information from the time we can only speculate.

If the disturbance was as complete as I suggest then many ecological processes have returned to these

streams. Riparian communities have developed, autotrophs and heterotrophs have colonised the stream channel (Table 1) and communities within riparian sediments appear capable of transforming organic matter and delivering it as dissolved organic matter to the stream (Table 2). The riparian vegetation delivered coarse organic matter, the mineral and fresh water springs delivered dissolved organic matter and in-stream primary production delivered autotrophic biomass (Table 1). These organic matter inputs represent the energetic fuel for the ecosystems within the streams. It should be of no surprise that such apparent recovery has taken place in the 150 years since the gold rushes. However, it is appropriate in the context of a stream rehabilitation conference to acknowledge that such apparent recovery has occurred, and has done so without any directed management.

3.2 Organic matter inputs: energy for the stream

Average annual organic matter input to a hypothetical one meter square section of stream can be determined from the mean litter input plus the mean photosynthetic input (GPP) plus the mean ground water input (Webster and Meyer, 1997). Quantifying the total amounts and relative contribution of each type of input helps in our understanding of the energetics of the stream.

3.2.1 Litter fall

Direct litter inputs at willow and native sites were very similar (approximately 540 g AFDW/m²/y, Table 1). They were nearly 50% higher at the mixed site. It is possible that the two vegetation communities 'combine' at the mixed site to increase canopy cover and thus litter fall, but low sample number requires caution in interpretation of results. Seasonal patterns were similar (data not shown), with lowest rates of litter fall in winter and a steady increase in rates through spring and summer. All sites showed a maximum rate of litter fall in late summer - early autumn.

Average direct litter fall for the watershed was 613 g AFDW/m²/y, which represents 75% of the total organic matter input.

3.2.2 Gross Primary Production (GPP)

Gross primary production (GPP) represents the sum of all photosynthetic activity by algae and plants growing in the stream reach. Table 1 shows an apparently greater GPP under the willow canopy compared to the native canopy. Care in interpretation is needed due to low sample size and the difficulty of comparing separate streams. However, differences appear marked. When averaged for the watershed I estimate GPP provides 127 g AFDW/m²/y, which represents 15.5% of total organic matter input.

	Native	Willow	Mixed	Watershed
Stream order	-	-	-	2-3
Catchment area (km ²)	-	-	-	88
Gradient (m/m)	-	-	-	0.017
Estimated mean annual discharge (L/s)	-	-	-	30
Organic matter inputs (g AFDW/m ² /y)				
Litterfall	534	543	763	613 (75%)
Gross primary production	30	224	-	127 (15.5%)
Groundwater DOM	-	-	-	78 (9.5%)
Respiration (g AFDW/m ² /y)				
Autotrophic respiration	15	112	-	64
Heterotrophic respiration	883	1217	-	1043
Organic matter and sediment storage				
Benthic organic matter (g AFDW/m ²)	503	5080	570	2051
Substrate bulk density (t/m ³) *	1.4	0.76	1.4	-
Organic matter stored per km (t/km)	1.0	30.5	1.1	10.9
Sediment stored per km (t/km)	139	426	139	235
Phosphorous stored in organic matter (kg/km)	9	275	9.9	98
Phosphorous stored in sediment (kg/km)	28	85	28	47

Table 1. Physical characteristics, organic matter inputs, respiratory outputs and sediment and organic matter storages for native, willow and mixed sites and mean values for the watershed. Watershed streams were assumed to be lined by equal lengths of each of the three riparian communities. * data from Wilson 1997.

3.2.3 Groundwater dissolved organic matter

An estimated 4 mg AFDW/L of dissolved organic matter (DOM) entered the stream corridor ecosystem from ground water sources. There were no observed differences in DOM contents in mineral or fresh waters or from the QBA or OBA aquifers.

Spring water delivered 4 mg AFDW/L of DOM to the edge of the riparian floodplain at a Spring Cr. site (Table 2). DOM content of the groundwater increased with proximity to the stream edge. DOM in the groundwater 1 m from the stream edge (14 mg AFDW/L) was close to twice that of the stream water (8 mg AFDW/L). Hydraulic head moved water from the spring toward the creek and diffusion alone would explain DOM delivery to the stream.

dist from stream, m	0*	1	2	3.5	5.25	6.9	9	11*
DOM, mg/L	8*	14	10	10	8	8	8	4*
GWT, cm	-	-1	0.1	-0.1	12	33	46	72
land surface, cm	-	23	39	50	41	66	79	72
Ksat, m/day	-	9.9	2.2	nd	0.1	0.15	0.4	-

Table 2: Dissolved organic matter (DOM as mg AFDW/L) content of sampled water, height of ground water table (GWT) and land surface relative to stream water surface and saturated hydraulic conductivity (Ksat) for 6 bores and spring and creek surface water (*) across an 11 m transect in January 1998. Shallow bores were augured to bedrock and sampled two weeks later (28/1/1998). nd=not determined.

Spring Cr. averages 1.9m in width and is 3425m in length between Hepburn Mineral Springs Reserve and the Spring Cr. - Sailors Cr. junction. Assuming the spring water DOM content is doubled (i.e. 8 mg AFDW/L) after it percolates through riparian sediments and the combined spring flows are 63.9 ML/y (Shugg 1996 for mineral spring flows and my data for fresh spring flows) then 78 g AFDW/m²/y was delivered by

groundwater to the lower reaches of Spring Cr. This is an expected maximum for the watershed as not all reaches have as many adjacent springs nor as wide a riparian floodplain as the Spring Cr. reach and many springs deliver water to the stream without percolation through riparian sediments.

An estimated contribution of 78 g AFDW/m²/y from groundwater throughout the watershed represents 9.5% of the total organic matter input.

3.3 Riparian roots and community respiration

Terrestrial photosynthesis (the riparian canopy) potentially delivers organic matter in the form of roots to the stream. At willow sites this organic matter input is potentially very large as the substrate is visually dominated by willow root mat. The large difference in organic matter storage between willow and native sites can be explained by the contribution of the willow root mat itself as well as trapped organic matter from other sources.

Circumstantial evidence of a biological role for willow root mats was observed in the community metabolism data. Table 1 shows the respiration rates at willow and native sites. Both autotrophic and heterotrophic respiration rates were greater at the willow site than the native site. The willow root mat may provide habitat and food for aquatic organisms and hence explain the observed increase in community respiration relative to native sites. Scouring of bedrock and cobble dominated reaches during high flows at native sites may limit organic matter retention and the size of algal populations. With less available food, less GPP and less habitat (bedrock severely limits the hyporheic zone), we may expect less community activity and thus a lower community respiration at native compared to willow sites.

3.4 Organic matter, sediment and nutrient storage

Sediment and nutrient dynamics are two significant issues facing stream, river and reservoir ecologists and managers. From an ecosystem perspective they are key players in the material cycling subsystem and from a management perspective they are key players in water quality issues including eutrophication, sedimentation and nuisance algae.

Amounts of benthic organic matter (BOM) were an order of magnitude greater at willow sites (5080 g AFDW/m², Table 1) than at native (503 g AFDW/m²) or mixed sites (570 g AFDW/m²). At willow sites the substrate was dominated by willow root mat and typical substrate depth to bedrock was 30 cm. At native sites the substrate was dominated by bedrock and cobble with typical substrate depth to bedrock of 5 cm. At the Sailors Creek Mixed site willow root mats had not extended to the mid-channel and the substrate was dominated by bedrock and cobble.

The mass of organic matter stored per km of stream was determined by multiplying the BOM data (Table 1) by the stream channel area (2000 m²/km for 2m wide stream channels) for native and mixed sites as the full depth of substrate was sampled, and multiplying the BOM data by stream channel area and by three as only a third of the substrate depth was sampled. This assumes BOM was uniform through the full 30 cm depth of substrate, which was apparently true when visually assessed on auger hole spoil. Thus it was estimated that willow sites stored 30 times more organic matter in the stream channel than native sites (Table 1). If we assume the organic matter contains 0.9% phosphorous (Kononova 1966) then an estimated 9 kg P/km and 275 kg P/km is in the organic matter stored in native and willow site stream channels respectively.

The combined mass of sediment and organic matter stored per km of stream was determined from substrate bulk density (Table 1) and substrate volume (substrate depth to bedrock times 2m width times 1000m length). By subtracting organic matter storage an estimate of sediment storage was obtained. Willow site sediment stores were three times those of native sites. Assuming the sediment contains 0.02% phosphorous (Caitcheon et al. 1995, Taylor 1983) then 85 kg P/km were stored in the sediment.

Aggradation (storage of sediment and organic matter within the stream channel) appeared to be a key feature distinguishing the exotic and native lined streams around Daylesford. If we assume there was 5 cm of substrate overlying bedrock prior to willow colonisation, then willow mediated aggradation has contributed to much of the Spring Creek channel bed being raised 25 cm in 50 years. At the mixed site, clear aggradation over bedrock was observable adjacent to willow lined banks with no or little sediment accumulation on bedrock in locations

free of willow root mat or adjacent to native riparian vegetation.

4. CONCLUSIONS

At my study location, willow sites appear able to retain more materials (sediment, organic matter and thus nutrients) and build more productive biological communities (as indicated by community respiration and GPP) than native sites. In addition they appear capable of continued succession. I believe these characteristics are not suggestive of a degrading ecosystem, rather that they can be considered indicators of ecosystem health (Rapport et al 1998). From the perspective of the Maximum Power Principle (Odum 1981) willow sites appear to be ecologically 'powerful'. This is not counter intuitive if interpreted in the context of altered land use, hydrology and nutrient status throughout the catchment since European settlement.

Rapport et al. (1998) suggested ecosystem health can be assessed using measures of vigour, organisation and resilience. My data suggests willow sites are more vigorous (measured in terms of community metabolism or gross primary production) than native sites. I suggest that this is related to the potential habitat and food (energetic) value of willow roots and their accompanying sediment and organic matter storages. Close scrutiny of organisation and resilience within native and willow lined stream habitats is needed to complete a picture of ecosystem health. However, to date most studies of biota within willow lined streams have shown few major biological perturbations (e.g. Schulze and Walker 1997, Read 1996, Beasley 1991, Koehn 1987, Pidgeon and Cairns 1981).

The Telescoping Ecosystem Model (Fisher et al. 1998) suggests that disturbance increases processing length of all materials. The greater the disturbance the more each subsystem (the stream and the hyporheic, parafluvial and riparian zones) is affected. Riparian forest removal is a major disturbance to stream corridor ecosystems. However, it is recommended on ecological grounds (Ladson 1997) when the forest is willow dominated. Willow removal, in concordance with the Telescoping Ecosystem Model, will logically increase processing length of all materials. This means materials such as organic matter, sediment and phosphorous will move further down the catchment before being captured and transformed. In the Daylesford district, the role I suggest willow roots are playing in organic matter, sediment and nutrient dynamics will cease on willow removal and there is no evidence from my data that native communities can mimic that role.

An interesting question to ask is where did these sediments and nutrients come from? If they are a result of land use practices in the catchments do willows potentially buffer downstream ecosystems from nutrients and sediments so released? These are core issues in understanding the 'material cycling' subsystem of ecosystems (Dickinson and Murphy 1998) and I believe

are equally important for management. Hence, consideration of sources and sinks of nutrients and sediments is an example of an ecosystem based approach to management.

Rapport et al. (1998), in reviewing the assessment of ecosystem health, suggest that as the “notion of health is so strongly associated in the public mind with a preferred state, it is especially vulnerable to political manipulation in its application to the environment”. For many of us at this conference that preferred state would be native riparian forest. My data suggests that willow removal will most likely result in sediment and nutrient mobilisation and may undermine apparently vigorous stream communities. A single minded approach to willows that demands all be removed for the sake of the environment appears to corroborate the fear of Rapport et al. (1998) that “further damage to the environment could be done in the name of promoting health”. An ecosystem approach to management includes the ecological function of willows. Such functions are not considered if they are managed solely on the basis of taxonomy.

I do not wish to undermine efforts to rehabilitate native ecosystems. Rather I wish to suggest that leaving apparently healthy ecosystems to continue undisturbed may avoid unforeseen ecological harm for downstream ecosystems. This is clearly acceptable practice when the healthy ecology is dominated by native plants, but is it also possible that it is appropriate practice when the vegetation is exotic?

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