Prediction of fluvial seed dispersal and long-term sustainability of riparian vegetation using sediment transport processes

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Abstract

Riparian vegetation throughout Australia has become increasingly fragmented and invaded by alien species, because of land clearing and development. Over the last 30 years, government and community groups have invested heavily in riparian re-vegetation and weed eradication programs. However, there is little understanding of the long-term sustainability of these plantings, which are often isolated pockets of riparian vegetation that are susceptible to weed infestation. Hydrochory, the dispersal of diaspores by water, is one process that enables plant populations to establish at some distance from their source, and may be important for ecological/genetic continuity between disjunct populations. In this paper a conceptual model framework has been developed that uses fluvial sediment transport and deposition process to understand the spatial dispersal of diaspores by water.

Keywords

Conceptual model, riparian zone, interconnectivity, rehabilitation, hydrochory

Introduction

Since European settlement in Australia many of our riverine landscapes have become degraded, with disjunct riparian plant populations that are heavily invaded by alien species. Over the last 20 to 30 years there has been extensive research and investment into riparian rehabilitation, as the importance of maintaining healthy river systems is being increasingly acknowledged (Alpert *et al.*, 1999). Previous research has focused on issues such as: species suitability (Webb & Erskine, 2003), vegetation structure and position (Abernethy & Rutherfurd, 1998), best management practices (Sweeney *et al.*, 2002), weed eradication techniques (Williams & West, 2000), and alien species invasion rates (Campbell *et al.*, 2002). However, there is little long-term understanding, at greater than 10 yr, of riparian vegetation sustainability, where the re-habilitated sites and remnant vegetation are often isolated patches that are susceptible to alien species infestation (Suding *et al.*, 2004).

Understanding of the interconnectivity and long-term sustainability of riparian plant populations may be enhanced by studying hydrochory, the dispersal of diaspores by water. Diaspores within the context of this paper are any seed, fruit or germinant derived from a plant. Hydrochory is one process that enables plant populations to establish at some distance from their source, and may be important for ecological and genetic continuity between otherwise disjunct populations (Andersson *et al.*, 2000a). However, there is little research in Australia on hydrochory compared to extensive research and modeling of fluvial hydrology and sediment dynamics in our river systems (Prosser *et al.*, 2001; Aksoy & Kavvas, 2005). Therefore, existing hydrological and sediment dynamics models could be used to develop a process model of hydrochory and improve our understanding of the long-term sustainability of riparian vegetation.

Hydrochory has generally been studied separately from fluvial and sediment dynamics, and only a few studies have shown links between these two fields. A relationship was first observed between sediment and diaspore deposition in northern European rivers by Nilsson *et al.*, (1993). Later a positive correlation was found between diaspore and sediment riverbank deposition at different elevations along the Dove River, England (Goodson *et al.*, 2003). Finally, results of laboratory experiments showed that diaspores (<50mg) were suspended at the same flow threshold as comparable sized sediment particles (Cerda & Garcia-Fayos, 2002). Therefore, this relationship between fluvial sediments and diaspores can be harnessed to help in understanding the processes involved in hydrochory.

Conceptual model framework

A hydrochory model is being developed at the catchment scale to help understand the interconnectivity between plant populations and broad plant dispersal patterns. The model will run with a yearly time step, although daily and monthly data will be used for the flow module (discharge) and seed abscission respectively.

Riparian plant populations can be highly influenced by local and upstream fluvial seed-rain, namely within the stream reach and from upstream. Therefore, a conceptual model framework has been developed through the integration of a plant population matrix model with sediment transport and deposition models (Fig. 1). The population module describes the population growth rate and resulting seed bank within each reach. The sediment transport and deposition models predict the spatial distribution of the diaspores, where diaspore size and specific weight classes are used as sediment surrogates to predict their transport between and deposition within reaches. Two spatial models are used, floating and suspended, as diaspore movement in these two classes is influenced by different environmental factors.

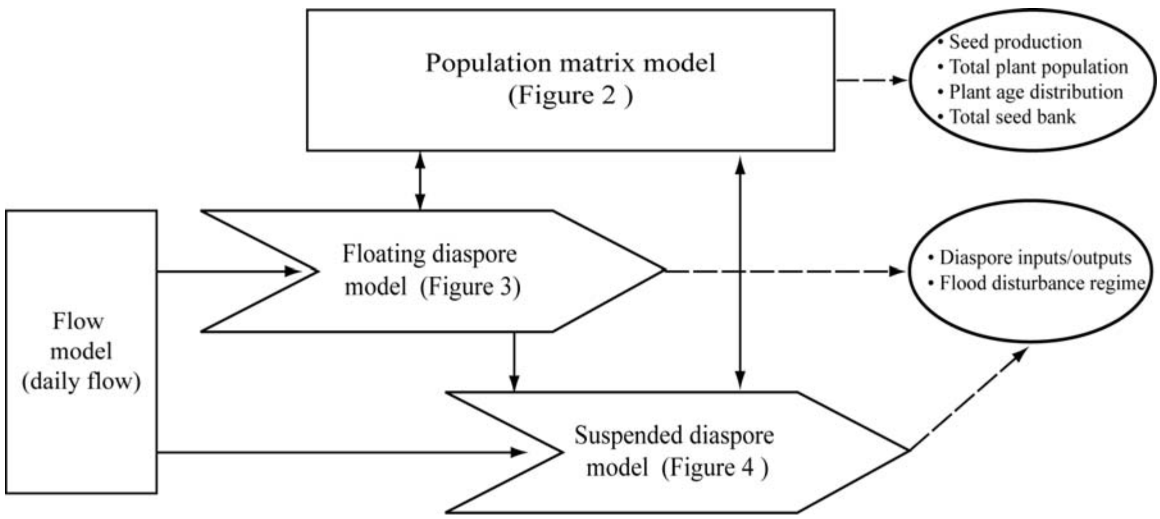

Figure 1. Conceptual model framework for fluvially dispersed diaspores at the reach scale.

Population matrix model

The population model is used to predict the plant population growth rate and viability within each reach (Fig. 2). The model uses both within-reach and between-reach inputs to understand the population dynamics. Within-reach inputs are used to predict plant development and seed bank germination rate. Between-reach inputs are fluvially transported diaspores, derived from the transport and deposition module, which is used to predict new genetic material that is entering a reach. As an analogy to sediment models, the population model is the equivalent to sediment erosion and deposition.

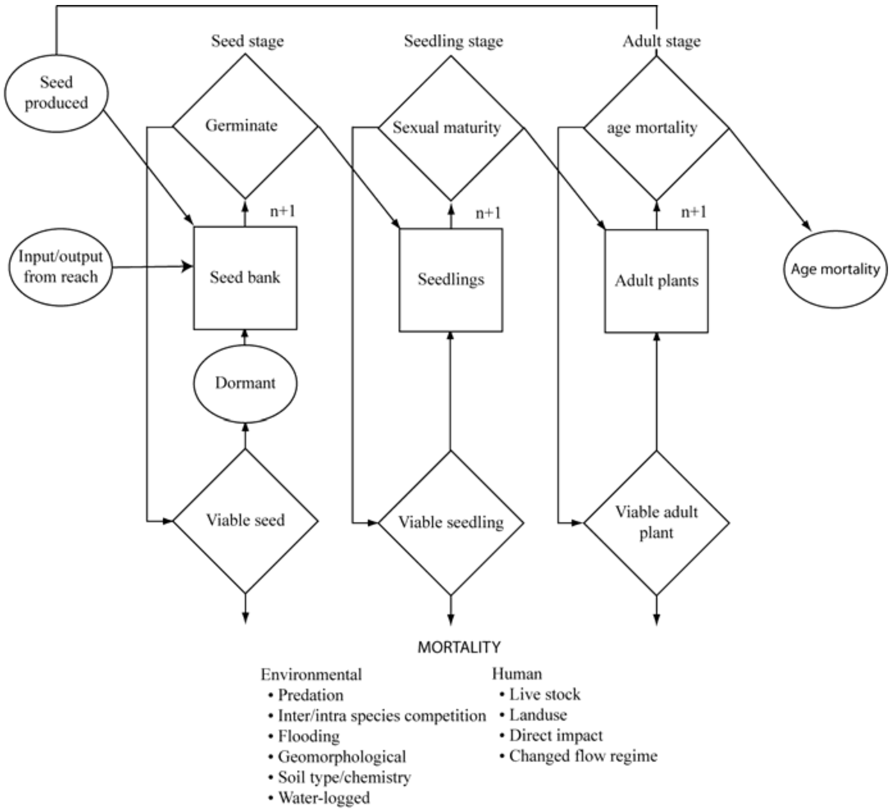

Figure 2. Conceptual framework for the population matrix model, at the reach scale.

Fluvial transport and deposition of diaspores

There are two media in which diaspores can be transported in water, floating or suspended. At the landscape scale hydrochory corresponds to an analogy of sediment transport and deposition; where washload equates to floating diaspores, and suspended bed-material load and bedload material corresponds to suspended diaspores. Washload for the context of this paper are fine clays which are carried in the stream and do not settle, or settle very slowly in low turbulence environments. Suspended bed-material load and bedload are material that are carried with the washload, but will settle in higher velocities (Gordon *et al.*, 1999). This analogy uses the size and specific density of the diaspores to describe their rate of transport and deposition in the river system. Although, unlike sediment, after time floating diaspores may move to the category of suspended as they become increasingly water logged.

Fluvial transport and deposition of floating diaspores

The model will presume that all floating diaspores that enter the stream channel are transported with the flow (Andersson *et al.*, 2000b; Riis & Sand-Jensen, 2006). The distance they are carried before being deposited on the river bank is determined by the flow velocity and channel roughness, where channel roughness is controlled by riparian vegetation cover, large wood debris and sinuosity of the channel (Andersson *et al.*, 2000b; Riis & Sand-Jensen, 2006). Likewise, washload is transported at the same velocity as the moving water, and settles only in still water zones, such as along the river-bank, which are determined by stream bank morphology and vegetation cover (Prosser *et al.*, 2001). Furthermore, in an Australian context, both diaspores and washload are supply limited, making the stream carrying capacity unlimited (Prosser *et al.*, 2001). The other main deposition sites for floating diaspores are the floodplain, reservoirs and lakes (Fig. 3).

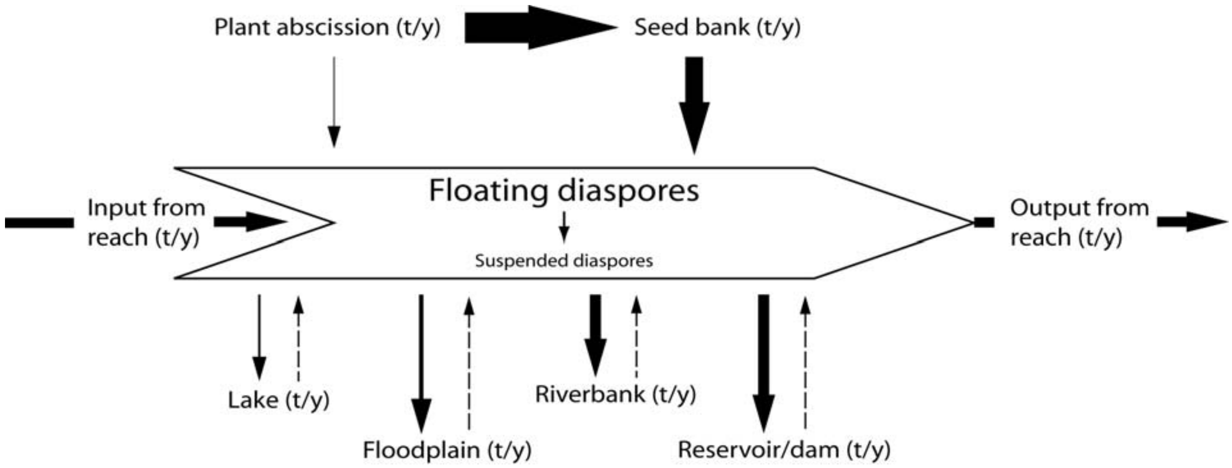

Figure 3. A conceptual model framework depicting the inputs and outputs of floating diaspores at the reach scale, where solid arrows denote primary movement, dashed arrows show possible secondary movement, and the size of the arrows denote the relative proportion of diaspore movement through the reach.

Upon inundation floodplains accrete most material that flows onto them (Danvind & Nilsson, 1997; Prosser *et al.*, 2001). As described for sediment retention by (Prosser *et al.*, 2001), the fraction of diaspores that enter the floodplain is likely to be the amount that is deposited. However to acknowledge that a proportion of floating diaspores, as with sediment, might re-enter the river channel, the residence time of the water on the floodplain is used to predict the deposition of diaspores (Prosser *et al.*, 2001).

Reservoirs and dams are barriers that decrease ecological connectivity between plant populations (Andersson *et al.*, 2000b). As with sediment accumulation, most floating diaspores are trapped behind these structures (Andersson *et al.*, 2000b). The quantity of diaspores that are trapped in the dam can thus be estimated from Brune's rule; although a percentage of floating diaspores also have a chance to float to the reservoir side, deposit and germinate (Andersson *et al.*, 2000a).

Lakes are low velocity areas that have a capacity to retain most material that enters. There is no research that the authors are aware of studying diaspore deposition in lakes. Therefore, as assumed for lake sediment deposition in the Sednet model (Prosser *et al.*, 2001), diaspores entering a lake will be treated as if entering a floodplain, where most are deposited. However, in the case of diaspores a portion will float to the lake edge, deposit and germinate (Andersson *et al.*, 2000a).

Fluvial transport and deposition of suspended diaspores

Suspended diaspores are supply limited, therefore their ability to be transported depends on stream power. The assumption made is that the threshold stream power required to mobilize sediment will be the equivalent threshold needed to transport diaspores of a similar size and specific weight (if <50mg) (Cerda & Garcia-Fayos, 2002). Stream power **Ω** is defined by:

$$\Omega = \gamma Qs \qquad (1)$$

where γ is water density (9810Nm^{-3}), Q is discharge (m^{3}s^{-1}), and s is stream reach gradient (mm^{-1}). Diaspores are classified into weight classes of 10mg to predict the stream power threshold required to mobilize them.

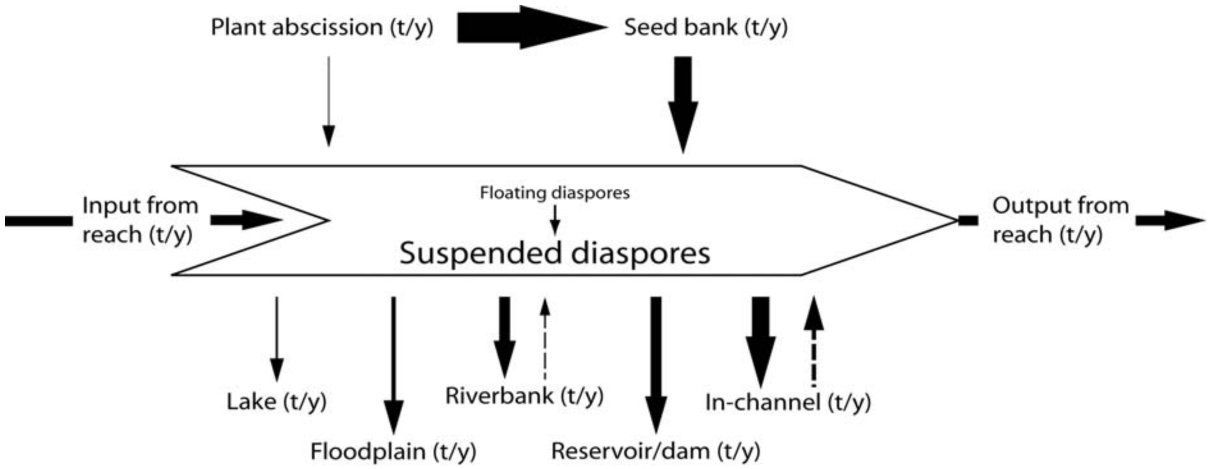

Figure 4. A conceptual framework of the inputs and outputs of suspended diaspores at the reach scale, where solid arrows denote primary movement, dashed arrows show possible secondary movement, and the size of the arrows denote the relative proportion of diaspore movement through the reach.

Suspended diaspores are deposited in low velocity areas (Fig. 4). Therefore, all suspended diaspores that enter lakes or reservoirs are assumed to be deposited. Likewise, the fraction of diaspores that enter a floodplain are all assumed to be deposited. However, the diaspores that are deposited on the riverbank may be re-suspended if another high flow event occurs, which has sufficient stream power for re-suspension and transport.

Discussion and conclusion

Seed dispersal models have mainly modeled individual species over short periods of time. This model focuses on the long-term viability of riparian vegetation where outside sources are needed for genetic and ecological continuity. By bringing together the fields of population dynamics and hydrology there is potential for greater understanding of the ecological inter-connectedness of our river landscapes.

The development of this model will help environmental managers to plan sustainable riparian planting programs. The model will also aid managers to understand issues such as: management levels needed for different degrees of connectivity between plant populations, the rate of alien species spread along a river system, and impacts of changed flow regimes on the dispersal patterns of riparian vegetation caused by climate change or river regulation.

This conceptual model is the first step towards the development of a process model of hydrochory. The development of the model will result in a generic process model that can be used on a variety of plant species and river systems, using equivalent sediment transport and deposition processes. The next step is to quantify the relationship between sediment and diaspores in a fluvial environment, then to develop a working version of the model. The model then needs to be calibrated and tested using experimental data sets.

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