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The Recovery Of Geomorphic Complexity In Disturbed Streams: Using Migrating Sand Slugs As A Model

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SUMMARY: Geomorphic complexity is an important measure of stream health, because highly structured habitats tend to contain more species than simply structured ones. Humans disturb fluvial systems, reducing the natural geomorphic complexity of streams. Considerable research has been carried out describing the impacts of disturbance on stream geomorphology, yet few studies have investigated the subsequent recovery of streams. An ability to determine the time scales of recovery will be extremely useful for prioritising stream rehabilitation projects. Streams that have been disturbed by large pulses of sand (sand slugs) or gravel provide good case studies of the recovery process. Sand slugs reduce the geomorphic complexity of streams as fine sediment fills in undercuts, backwater zones, edgewater habitats and pools and riffles. In this paper we hypothesise that 'the amount of recovery in the stream is a function of the time since the slug passed, and the range of flows experienced in that time'. A number of methods for measuring the variability in geomorphic complexity, including statistical techniques and simulation models are briefly discussed.

THE MAIN POINTS OF THIS PAPER

- Geomorphic complexity is important for habitat and therefore aquatic biology;
- In most cases disturbance decreases the geomorphic complexity of streams, sand slugs are a good example of this process;
- The process of recovery of geomorphic complexity following disturbance by sand slugs is an important area of research in the field of stream rehabilitation.

1 INTRODUCTION

This paper discusses the recovery of geomorphic complexity in streams following human disturbance, using sand slugs as an example. Geomorphic complexity is defined in this paper as the variation in channel shape, flow variability, substrate composition and vegetation characteristics of a channel. Recovery is the return of part or all of the original geomorphic complexity to a stream reach following disturbance. Geomorphic complexity is important as highly structured habitats with heterogenous physical structure, tend to contain more species than simply structured ones (Downes *et al.*, 1995). A natural diversity of native organisms tends to be a good indicator of a healthy stream. For this reason, a complex stream morphology and hydraulic environment is often considered to be one of the primary targets for stream rehabilitation (Brookes and Sear, 1996).

Human disturbance of stream channels often reduces geomorphic complexity by triggering erosion and deposition. Following disturbance, the stream may recover some of its complexity over time (see Brierley, this volume). Thus, one of the central principles of stream rehabilitation is that managers should work with this recovery (see Downes, Eskine and Webb this volume) when setting priorities for stream rehabilitation (see Rutherfurd, this volume).

Most research into fluvial geomorphology has centred on disturbance (erosion) and much less effort has gone into understanding how streams recover. An exception to this is the work on the recovery of incised streams (see Schumm and Harvey, 1984; Simon, 1989; Cohen, this volume). Thus, both qualitative and quantitative assessments of stream recovery processes are required.

This paper will initially define the term geomorphic complexity and discuss the concepts of disturbance and recovery. We will then present a case study of how geomorphic complexity returns to a system following disturbance by sand slugs. This story of disturbance and recovery will be illustrated by preliminary observations from the Glenelg Catchment, Western Victoria.

2 WHAT IS GEOMORPHIC COMPLEXITY?

Geomorphic complexity can be described as *variation* in the stream's *channel morphology, flow velocity, substrate composition and vegetation characteristics.*

- *Variable channel morphology* refers to the cross sectional surface morphology as well as the longitudinal variation of the bed profile. In general, the greater the surface area and variability of substrate types, the more diverse the range of habitats that are available for colonisation by organisms such as

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macrophytes, fish and macroinvertebrates. Hughes *et al.*, (1986) described a complex fluvial system as having “high heterogeneity in channel width and depth (shallow riffles, deep pools, runs, secondary channels, flooded backwaters, sand or gravel bars, and islands), abundant large woody debris (snags, root wads, log jams, brush piles), coarse bottom substrate (gravel, cobble, boulders), overhanging vegetation, undercut banks, and aquatic macrophytes”.

- *Flow variability* is generally a function of channel shape; that is, specific flow types produce specific morphological forms and vice versa. The more variable the channel morphology the more varied the flow types for a given reach (there is a feedback relationship between flow and morphology). Numerous studies have shown that the ecology and distribution of individual species are strongly influenced by habitat volume (water depth), current velocity, food availability, and thermal regime, all of which are influenced by flow hydraulics (Poff and Allan, 1995).

- *Substrate composition* measures grain size variation. Grain size is considered as an essential variable to the distribution and abundance of organisms (Des Chatelliers and Reygrobellet, 1990). Poff and Allan, (1995) discuss how the substrate is vital for the food, shelter and/or reproduction requirements of species. When the substrate becomes dominated by a single grain size, such as in the case of sand slugs, the habitat potential of the sediment is reduced. Fine sediments affect invertebrates, as well as fish eggs and larvae. The function of the substrate as a refuge from predators and swift currents, and as a feeding area, is also reduced.

- *Vegetation characteristics* include the proportion of woody and non-woody vegetation both on the banks and in the channel. Large organic debris can have a major control on channel form and process (see Marsh *et al*, and Brooks this volume). Macrophytes and algae are also an important habitat feature for macroinvertebrates.

Geomorphic complexity has been shown to be extremely important for instream habitat. Stream ecologists have long recognised that physical environmental heterogeneity influences species richness and abundance (Poff and Ward, 1990). It is also increasingly acknowledged that geomorphological surfaces form the template for the development of riparian ecosystems. There is a growing argument that abiotic conditions such as physical habitat, are a more achievable target for describing stream recovery than are biological factors such as density, diversity or production of certain species (Brookes and Shields, 1996). For this reason, geomorphic complexity is considered an appropriate measure of stream recovery.

2.1 Measuring changes in Geomorphic Complexity

When discussing stream recovery, it is assumed that a recovered stream or reach will have a greater amount of geomorphic complexity than a stream that has been disturbed. Thus, tools for evaluating changes in geomorphic complexity are required.

A range of tools, ranging from complex statistical techniques (multivariate analysis, the Shannon-Weiner function) to sophisticated computer models (The Physical Habitat Simulation Model or PHABSIM), have been used to determine the variability in hydraulic habitat and physical heterogeneity in streams. These tools can be used to calculate whether there has been an improvement in the level of geomorphic complexity of a stream reach following the appropriate data collection process.

It is not the purpose of this paper to discuss these concepts in detail. More detail and examples of the application of these concepts can be found in Bovee (1982); Brown (this volume); Irvine *et al.*, (1987); Stewardson and Gippel (1997); Stewardson (1998); Stewardson (this volume).

2.2 Variability of Geomorphic Complexity within a catchment

It is also important to note that geomorphic complexity operates at a variety of spatial scales resulting from the systematic variation of geomorphic units in the downstream direction (Brussock *et al.*, 1985). Stream channel form changes predictably, producing characteristic patterns of flow, depth and substrate form; hence, different types and amounts of geomorphic complexity can be found at different points in the catchment.

Numerous studies have been conducted that describe the variation of fluvial processes and geomorphic changes within a catchment. Figure 1 outlines how four characteristics (stream power, erodibility, sediment movement and substrate size) vary with distance downstream.

The recovery process discussed in this paper will therefore be considered over a variety of scales (catchment, reach, unit and substrate) as recovery at any one level, does not imply recovery at the other scales.

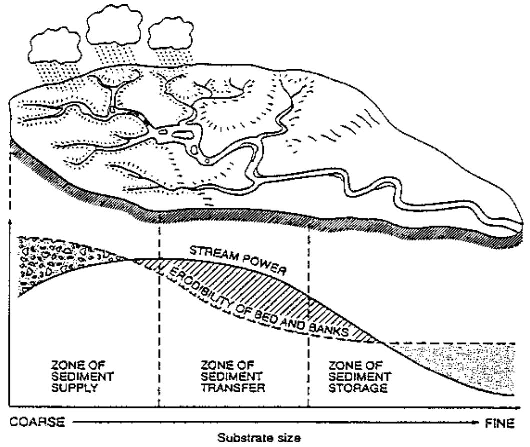

Figure 1: Variability in stream power, erodibility, sediment movement and substrate size with downstream distance (Brookes and Shields, 1996) .

The rate and pathway through which a stream re-develops its geomorphic complexity following disturbance by sand slugs will therefore vary depending on which area of the catchment has been disturbed.

3 DISTURBANCE AND GEOMORPHIC COMPLEXITY

For centuries, humans have reduced the geomorphic complexity of streams through changes such as dams, mining and agriculture. These types of disturbance all act to change the natural hydraulic, biological and geomorphic conditions of a channel, usually leading to reduced complexity. Disturbance can be considered as ‘any relatively discrete event in time that disrupts ecosystem structure or the physical environment’ (White and Pickett, 1985).

The terms ‘press’ or ‘pulse’ are used to distinguish between types of disturbance (Underwood, 1996). A pulse disturbance is of limited and easily definable duration (eg. floods) whereas press disturbances are longer and frequently involve changes in the catchment or river channel (eg dams, mining or logging). The terms press and pulse refer to the temporal scale of disturbance and do not take the magnitude of the disturbance into account. Thus, it is important to determine not only the magnitude of a disturbance, but also whether it is a press or pulse disturbance. Both of these factors will determine the rate and processes of recovery.

4 WHAT IS RECOVERY?

In general, a disturbance such as a sand slug may lead to a new geomorphological state that is more or less complex than the original condition. A number of authors have qualitatively discussed the morphological recovery of streams. Simon (1989), developed a six stage model of channel evolution for disturbed alluvial channels and Schumm and Harvey (1984), described channel recovery for incised channels as a function of equilibrium stages. Unfortunately, these qualitative descriptions of channel recovery have limited use for determining stream recovery timescales. Other authors such as Brookes and Gregory (1988), did apply time scales to the disturbance recovery period, however, they do not provide detailed information on the physical changes that occur during the specified time periods. Table 1 outlines some of the recovery time scales that have been documented in the literature (see Brookes and Gregory, 1988; Milner, 1996 for more detail).

Brookes and Sear (1996), described channel recovery in terms of mean stream power. They identified that at mean stream powers less than 15 W/m^2, deposition of sediment results in the smothering of instream features, including pools and riffles. Above a threshold of 35 W/m^2, straightened channels tend to recover naturally, and it is only channels with very high energies which regain some, or all of their original sinuosity (Brookes and Sear, 1996).

Based on studies of channel recovery, it is possible to list a number of general recovery indicators for streams. These include: re-development of pools and riffles, bench formation, terrace development, re-development of a meandering thalweg, slope re-grading, cross sectional adjustment, re-working of failed material, variable flow patterns, armouring and heterogenous sediment and vegetation colonisation. These features are generally indicative of equilibrium channels and can therefore be considered as the end-point (equilibrium state) of the recovery spectrum.

Table 1: Examples of recovery timescales following disturbance.

Type of disturbance	**Place and year**	**Recovery Rate**	**Source**
Water Control and diversion systems	Rio Grande (1923)	>50 years, the system is still changing	(Everitt, 1993)
Dredging and straightening	Obion-forked Deer River 1959-1973	> 40 years	(Simon and Hupp, 1987)
Channelisation	Big Pine Ck (Indiana) 1932	Estimated rates are approximately 165 years	(Barnard and Melhorn, 1982)
Logging	?	Channel recovery of riparian vegetation ranges from 100-200 yrs	Sullivan (1987) in (Milner, 1996)

4.1 How do you know when a stream has recovered?

When attempting to determine if a stream has recovered, it is important to be able to quantify the potential recovery end-point for the stream. This allows the recovery process to be measured against space and/or time. It is also helpful for evaluating the costs associated with rehabilitation, particularly in cases where it is identified that the system will not recover without the use of rehabilitation structures.

There are a number of different ways to determine recovery end-points. Hughes *et al.*, (1986) proposed the idea of using reference sites as a basis for providing geomorphic, hydraulic and biological data. These he argued, could be used as bench-marks, for the level of recovery required at disturbed sites. This is because field assessments of impacted streams require a control or at least an estimate of attainable conditions. Hughes *et al.*, (1986) outlined four approaches for estimating the recovery end-point of a stream; forested streams, historical data, up and downstream sites, and before and after studies. These methods, combined with aerial photo analysis and historical research, will provide a picture of the appropriate condition of a disturbed reach.

Another method for determining if a stream has recovered is by using ‘space-for-time’ substitution. This technique suggests that the longer the time period since the disturbance occurred, the more ‘recovered’ the stream will be. This technique was used by Schumm and Harvey (1984) to develop the incised stream recovery model. This method could also be applied to sand slugs. The method suggests that the reach furthest upstream from the end of the sand slug should be the most recovered. Using this method it is possible to measure changes in geomorphic complexity. Sand slugs will now be presented as a case study of disturbance and recovery.

5 SAND SLUGS: A CASE STUDY OF DISTURBANCE

5.1 How sand slugs reduce geomorphic complexity

Sand slugs are an appropriate case study to examine the process of recovery in fluvial systems following disturbance. The reason for using sand slugs to investigate the processes of recovery is based on the common industry assumption that once the slug has passed through the stream, the stream will return to its original complexity (see Figure 2).

Sand slugs tend to move through the channel as an attenuating wave, ie. the sand slug gets longer and lower as it proceeds. Thus, slugs that have a relatively well defined back end are the most suitable for studying the recovery of geomorphic complexity.

There are numerous cases of sand slug disturbance in the Australian literature. Examples include the Ringarooma River (Tasmania) (Knighton, 1989), Glenelg River (Victoria) (Rutherfurd and Budahazy, 1996), Tambo River (Victoria) (Erskine *et al.*, 1990), Goulburn River (NSW) (Erskine, 1994), Hunter Region (Erskine, 1996). These studies describe the response of a channel affected by a sand slug. In general, channels may aggrade and widen, pools can infill, the bed material can fine, and channel roughness decrease. The morphological variability of channel structure is destroyed as sediment fills in undercuts, backwater zones, edgewater habitats, pools and riffles. It may also cover any existing woody debris and bed-rock outcrops which have been shown to be important substrates for habitat, feeding and lifestyle requirements for numerous organisms.

5.2 A Recovery Hypothesis

The hypothesis that we aim to investigate is that the level of geomorphic complexity will be the same following disturbance as it was before the arrival of the sand slug. Figure 2 schematically describes the expected recovery process in a stream that has been disturbed by a sand slug. It implies that the level of geomorphic complexity that was present before the disturbance, will return to the system after the sand slug has passed through. That is, if recovery can be estimated by some measure of geomorphic complexity, then morphological (and so biological) complexity should increase upstream away from the sand slug, back to its pre-disturbance level. If we know the rate that the sand slug is travelling (which decreases downstream) then we immediately have a measure of the rate at which a stream recovers from sand slug disturbance.

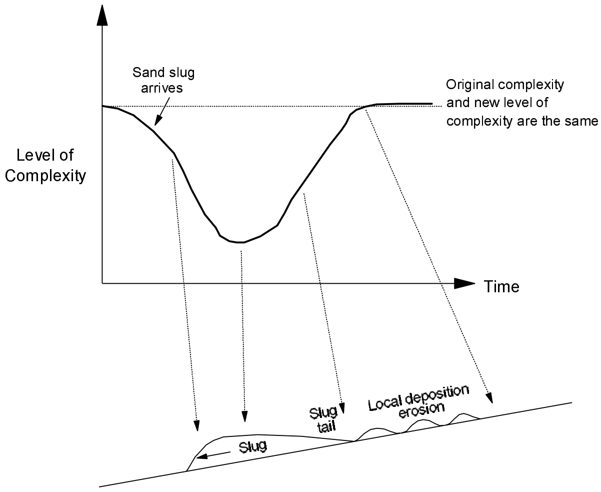

Figure 2: Expected pattern of the recovery of geomorphic complexity following disturbance by sand slugs.

5.3 Examples of sand slug disturbance in the Glenelg Catchment

The Glenelg Catchment lies on granite lithology in Victoria's south west. The human impacts of vegetation clearing, channel incision, river regulation and de-snagging have all resulted in the Glenelg River and its tributaries being filled with more than 6 million m^3 of sand over the last century (Rutherfurd and Budahazy, 1996). Most of the tributaries of the Glenelg River are incised streams, that are filled with sand, and are continuing to re-incise as the sand moves through. The supply of sand to these streams has declined over the last 30-40 years and the slugs are now migrating downstream.

The massive excess of sand in the Glenelg catchment provides a good opportunity to observe how sand slugs disturb streams and reduce a stream's geomorphic complexity. Some of the disturbance features observed in the Glenelg and its tributaries include: channel over-widening, little variation in the cross section, flat featureless beds of sand void of habitat units such as pools, riffles and backwater zones and uniform substrate sediment size. Channel incision following the removal of sand from the bed also means that any vegetation present is minimal and unstable.

Figure 3: Deep Creek, a tributary of the Glenelg River, that has been completely filled with sand leaving a flat featureless bed.

6 RECOVERY POTENTIAL OF STREAMS IN THE GLENELG CATCHMENT

Field observation of a number of tributaries of the Glenelg catchment allowed for a preliminary assessment of recovery features for streams affected by sand slugs. However, due to the combined impact of sand slugs and channel incision in the Glenelg Catchment, the process of recovery was found to be more complex than first discussed in Section 5.2.

Bryans Creek and Deep Creek are both incised tributaries of the Glenelg River. In both streams, the level of sand is decreasing as the slug moves through. Both streams were chains of ponds before settlement but they will not return to that state. Instead they move through a complex set of changes. The slug invades the incised stream. As the slug moves through, there is an initial increase of complexity as bars and pools are formed by the remaining sand, which is also colonised by reeds. However, the channel begins to incise again, destroying the developing complexity. This, the pattern of disturbance and recovery, looks more like Figure 4 than Figure 2.

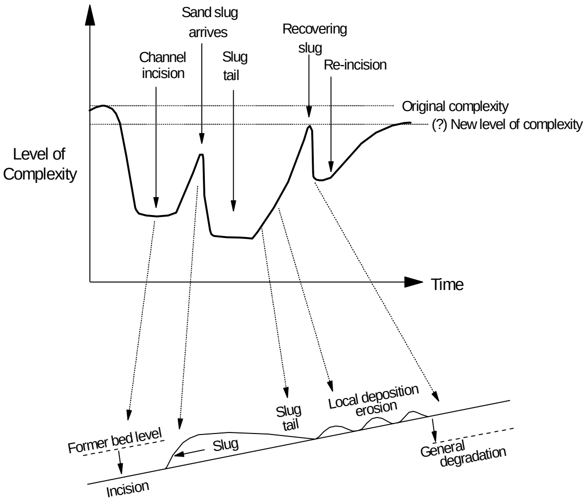

Figure 4: Typical pattern of the changing level of geomorphic complexity of incised streams that have been affected by sand slugs.

Where sand has invaded a stream that was not incised, a quite different pattern of complexity has developed. Mathers Creek (Glenelg Catchment), for example, has filled with sand, becoming a series of long pools and wetlands colonised by macrophytes. These new wetland areas appear to be permanent and stable.

7 DISCUSSION AND CONCLUSIONS

This preliminary investigation into the recovery of geomorphic complexity following disturbance by sand slugs has shown that the recovery pathway is non-linear. In addition, the recovery process will vary between streams and even between reaches depending on the idiosyncratic properties of each stream.

Thus, it is expected that the recovery process will be different between incised and non-incised streams. We will therefore be continuing this work by investigating simple sand slugs related to mining sediments in non-incised streams.

In the light of the investigation presented, a number of other questions are raised. Does recovery potential have a detectable regional component that reflects large-scale differences in geomorphology and stream flow characteristics? Can the recovery process for sand-slugs be sped-up by artificial remediation?

Knowledge of the trajectory and processes of recovery following disturbance will be important because:

- Existing models, such as those by Brierley (this volume) and Rutherfurd (this volume) rely on knowledge of the end-state or trajectory of a system. Research into these areas has been extremely limited to date;

- An understanding of the limiting variables related to the recovery process will allow stream managers to accelerate the process of stream recovery eg pool-riffle sequencing, LWD;
- Being able to determine the recovery trajectory of streams will allow more informative decisions about the distribution of rehabilitation money, such as NHT grants, to be made.

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