Preface

Source-to-sink sedimentary cascades in Pacific Rim Geo-systems

Introduction

This book outlines source-to-sink sedimentary cascades in differing geo-systems around the Pacific Rim. Case studies are presented from Japan, the Philippines, Thailand, Indonesia, New Zealand, the United States and Australia, showing the differing nature of sediment source, transfer and sink zones in these different environmental settings. Patterns and rates of sediment delivery through drainage nets are related to the tectonic, climatic and land use settings in which the studies were performed. This editorial presents an overview of these case studies, highlighting their scientific and management applications. Potential themes for future research are outlined.

In recent years, variability in spatial and temporal patterns and rates of sediment transfer, and their differing environmental and social consequences, have been highlighted in differing regions of the world. Such concerns are especially evident in Japan, where population and infrastructure requirements have been extensively developed along river courses. In many instances, sediment disasters and flooding are caused by riverbed changes associated with downstream propagation of materials derived from mountainous rivers and alluvial fans. Although many river systems have been subjected to extensive programs of dam building and regulation, perspectives on environmental management in Japan, and elsewhere, are changing, and overly-engineered river courses are no longer seen as a sustainable basis for long-term landscape recovery. Many engineers and river scientists are striving to reframe environmental solutions in terms of natural recovery processes and associated implications for aquatic ecosystem functioning. Such insights must build upon solid baseline understanding of spatial and temporal variability of the various components of sedimentary cascades (cf., Walling and Webb, 1993; Wolman, 1977), as demonstrated in this book.

Changing perspective in environmental management are recognised explicitly by the Ministry of Land, Infrastructure and Transportation (formerly the Construction Ministry), the sponsors of this book, who, since the early 1990s, have emphasised the need for a more harmonious approach to assessment of landscape changes and mitigation of sediment disasters. The Nippon Alps Sabo Centre(Matsumoto Sabo Work Office), as part of the Japanese Ministry of Land, Infrastructure and Transport, has adopted a future perspective on landscape management, recognising the need to maintain and enhance ecosystem structure and function (see Nishiyama, this volume - subsequent references with no date refer to this volume). Concerns do not only relate to river management issues, but the broader off-site (indeed, occasionally offshore) responses of landscapes to altered catchment sediment budgets. For example, depletion of sediment transfer associated with dam developments may result in accelerated rates of coastal erosion and shoreline retreat (see Mano).

Management responses in Japan are now changing, and downstream sediment movement is promoted at low flows, reflecting broader (catchment-scale) perspectives in management of sediment movement through landscapes. In developing these approaches, international perspectives on sediment budgets are being integrated into sediment management planning; hence, the support for this book. In the chapters that follow, studies on sedimentary cascades from tectonically active landscapes, including examples from Japan, the Philippines, Thailand, Indonesia, New Zealand and the Pacific Coast of the United States, are shown to contrast starkly with various case studies from the tectonically stable Australian continent.

Pacific Rim context

Various physical attributes of the regional setting for each catchment case study are summarised in Table 1. Catchment areas range from 5-30,800 km^2, with relief ratios ranging from 0.1 and 0.0001 and mean annual rainfall ranging from 250 mm to more than 4000 mm. As relief ratio indicates the potential energy for mass wasting and for the sediment transportation by flooding water, it provides a good guide to potential sediment mobility through drainage nets. However, sediment availability and lithology are critical here, and they vary markedly among the various case studies.
In terms of sediment mobility, annual rainfall can be as important as the relief ratio. The Sacobia-Bamban River, Phillipines (Sakatani and Inoue), and the Putih River, Indonesia (Kaneko et al.), have much higher relief ratios than the other rivers, with annual rainfalls of 1990 and 4400 mm respectively. Although Creightons and Ringarooma Creeks, Australia (Bartley et al. and Bartley and Rutherfurd), and Caspar Creek, USA (Ziemer), also have relatively high relief ratios, their mean annual rainfall is less (600, 800 and 1190 mm respectively). On the other hand, Oyabu and Yatate Creeks (Kasai and Marutani) are located in areas with much higher rainfall and relief ratios.

Landscapes around the Pacific Rim are subject to extreme events in the form of earthquakes, cyclones, and volcanic eruptions. Earthquakes may generate sediment and/or predispose it for transport, cyclones both generate and transport sediment through the landscape, while volcanic eruptions generally load the landscape with sediment. The relative frequencies of such events are an important control on sediment yields in tectonically active landscapes. Where all three types of events have a high frequency of occurrence, for example in Japan, sediment yields tend to be high. However, extreme events cannot, in themselves, explain the variable nature of sedimentary cascades in differing geo-systems around the Pacific Rim. For example, indices of variability for rainfall, runoff and discharge are as high, if not higher, in Australia relative to other parts of the globe, and it is sediment availability that drives the nature and rate of sediment movement (and its consequences) in Australian landscape settings.

Differences in measurement approaches and techniques in the different case studies reflect the rate of sediment movement, the diversity of timeframes over which adjustments to sediment budgets have taken place, and the spatial scale of differing catchments. Studies in Oyabu and Yatate Creeks in Japan (Kasai and Marutani), Creigthons and Wannara Creek in Australia (Bartley et al. and Crighton and Gore respectively), and Casper and Redwood Creeks in the United States (Ziemer and Madej and Ozaki respectively) have undertaken sequential monitoring and measurement of riverbed changes over short timeframes. Analyses of sediment budgets in Bega catchment in Australia (Fryirs and Brierley) and Waipaoa and Waiapu catchments in New Zealand (Page et al.) have been based on field measurement of long-term sediment budgets using age and volumetric analyses of differing geomorphic surfaces. Finally, the sediment budget of Mae Klong River (Maita) and many Japanese rivers, such as Ishikari River (Kuroki et al.), Abukuma River (Mano), Hime River (Nishiyama et al.) and Azusa River (Nishiyama) are monitored by measuring sediment retention rates in dams or by coastal measurements.

The pronounced diversity of physical characteristics of Pacific Rim geo-systems has particular implications for catchment-scale sediment budgets. The consequences of these 'natural' processes, however, are accentuated by the differing population densities, societal structures and land use practices that characterise each region. These differences, among other factors, result in the differing scale, focus and management applications of the various case studies presented here.

Environmental setting as a control on the nature and rate of geomorphic process activity

The nature and rate of differing geomorphic processes that deliver sediments to valley floors (e.g. mass movement mechanisms such as debris flows, earth flows, etc., relative to sheetwash and creep mechanisms, relative to gully processes) vary markedly in tectonically stable and tectonically active settings. This results in significant variability in sediment transfer relationships, with rapid transfer of materials in some landscapes, extensive residence times of storage units in others, and landscapes in which sediment transfer linkages may be spatially and temporally disconnected. Sediment production, storage and output are conditioned by many factors that set the threshold for movement. Thresholds may shift

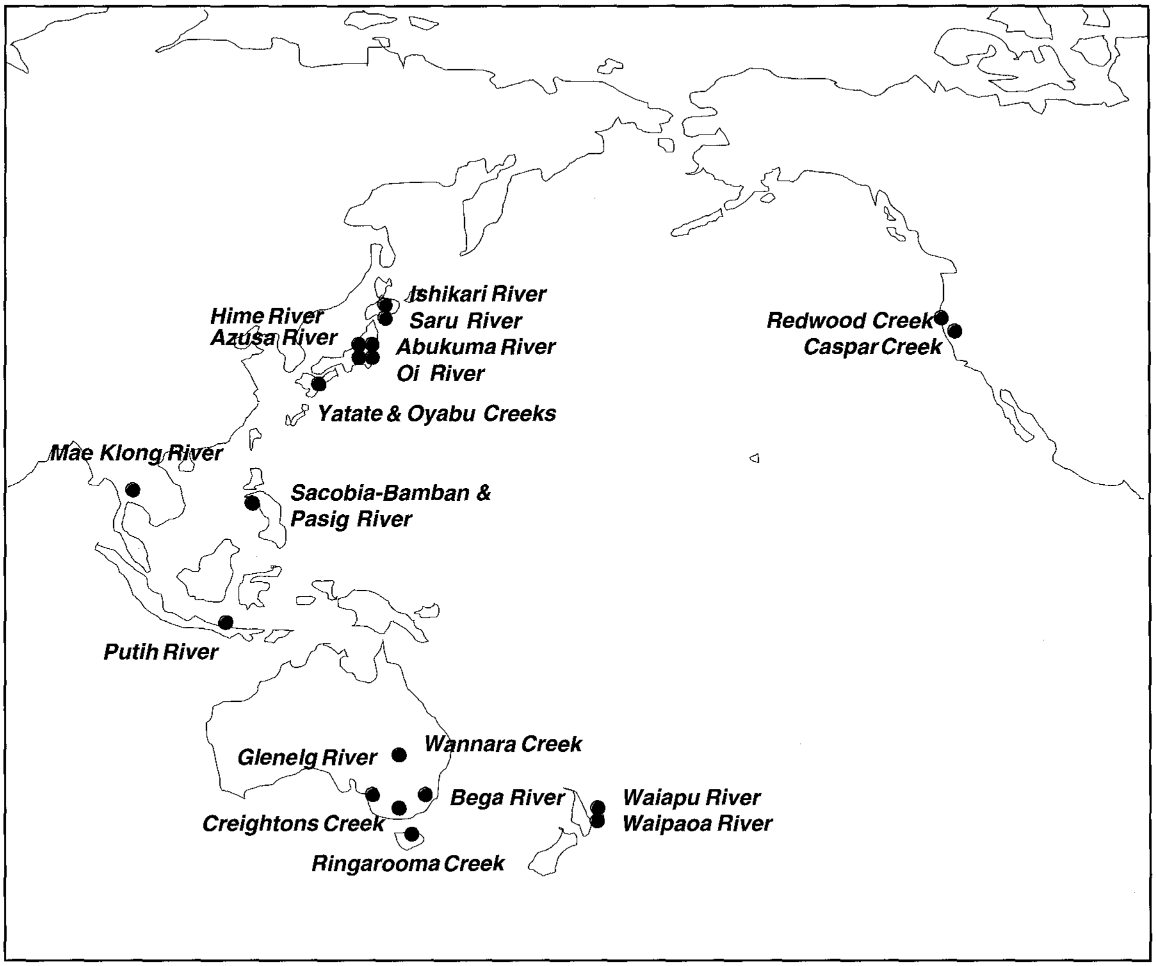

Figure 1 Location map of sedimentary cascades in differing geo-systems around the Pacific Rim

with a change in climate and/or vegetation (cf., Wolman and Gerson, 1978), or in response to the magnitude and frequency of forcing factors such as volcanic activity, earthquakes and storm events. Without sufficient recovery time for soils to reform, the thresholds become higher with each successive event. Spatial and temporal variations in thresholds, process dominance, and effects due to prior events, make it difficult to determine the role that events of a given magnitude play in the production and dispersal of sediment in large drainage basins.

The nature and rate of sediment delivery from slopes, controls on material storage along valley floors, and the threshold conditions under which materials are retained or reworked by channels, vary markedly in space and time. Sediment disasters associated with massive slope failure and accelerated valley floor aggradation are prominent in parts of tectonically uplifting landscapes (see Nishiyama, Sakatani and Inoue, Page et al.). In contrast, depletion of sediment from disturbed valley floors characterises some parts of tectonically stable landscapes, where limited sediment availability may compromise the potential for geomorphic recovery of river courses (e.g. Fryirs and Brierley). Upstream sediment sources may be decoupled from lowland basins, whether associated with natural sets of landscape forms and processes (e.g. Madej, Page et al.) or human-induced sediment traps (e.g. Shimizu and Araya, Kuroki et al.).

The nature of sediment source, transfer and accumulation zones, the sensitivity of landscapes to change, and associated implications for catchment-scale sediment budgets in differing environmental settings around the Pacific Rim relate not only to landscape setting but also to climate setting. For example, many humid coastal zones are prone to impacts from extreme events, such as monsoon and cyclone events. The geomorphological and sedimentological consequences of such events vary markedly in differing settings, conditioned in part by sediment availability, regional topography and landscape history. In large diverse catchments like the Waipaoa (see Page et al.), low to moderate magnitude storms have a high enough

Table 1 The regional setting for the case studies presented in this book

Catchment, Country, Author	Catchment area (km^2)	Regional geology	Mean annual rainfall (mm)	Relief ratio (*) (km^{-1})
Yatate Creek, Japan, Kasai and Marutani	25	Highly weathered granite	3500	0.0436
Oyabu Creek, Japan, Kasai and Marutani	5.2	Crushed and sheared mudstone, shale and sandstone	3500	0.0940
Azusa River, Japan, Nishiyama	599	Mudstone, chert and sandstone	1220	0.0034
Hime River, Japan, Nishiyama and Miyazaki	722	Granite and sedimentary rocks	1960	0.0041
Saru River, Japan, Shimizu and Araya	1350	Mudstone and sandstone	1250	0.0015
Ishikari River, Japan, Kuroki et al.	14,330	Volcanic and sedimentary rocks	1300	0.0001
Abukuma River, Japan, Mano	5400	Granite, andesite, basalt and volcanic products	1100-2800	0.0003
Oi River, Japan, Maita et al.	1300	Sandstone and siltstone	2000-3000	0.0025
Sacobia-Bamban River, Phillipines, Sakatani and Inoue	44.3 (before eruption) 22.3 (after piracy)	Volcanic rocks; pyroclastic flow materials	1990	0.0372 (before eruption) 0.0269 (after piracy)
Pasig River, Phillipines, Sakatani and Inoue	21.3 (before eruption) 45 (after piracy)	Volcanic rocks; pyroclastic flow materials	1990	0.0329 (before eruption) 0.0267 (after piracy)
Mae Klong River, Thailand, Maita	30,800	Limestone, sandstone, mudstone and shale	900-2100	0.057
Putih River, Indonesia, Kaneko et al.	26.6	Volcanic breccia, tuff breccia, tuffaceous ; claystone	4400	0.1111
Waipaoa River, New Zealand, Page et al.	2205	Sandstone and mudstone	1000->2500	0.0005
Waiapu River, New Zealand, Page et al.	1734	Sandstone and mudstone	1600->4000	0.0010
Redwood Creek, United States, Madej and Ozaki	720	Sandstone, mudstone, schist	2000	0.0021
Caspar Creek, United States, Ziemer	9	Sandstone, siltstone, mudstone, and conglomerate	1190	0.0769
Bega River, Australia, Fryirs and Brierley	1840	Granite, granodiorite and metasedimentary rocks	750-1200	0.0004
Wannara Creek, Australia, Crighton and Gore	592	Sandstone, siltstone and claystone	254	0.0003
Glenelg River, Australia, Rutherfurd	12700	Granodiorite	750	0.00005
Creightons Creek, Australia, Bartley et al.	141	Granite	600-800	0.0075
Ringarooma Creek, Australia, Bartley and Rutherfurd	912	Granite, sedimentary slates, sandstone and basalt	980	0.0090

(*) Relief ratio: elevation/ catchment area (Mino, 1968) frequency of recurrence cumulatively to outweigh large, rare events as transporters of sediment (Trustrum et al., 1999). This is in agreement with Wolman and Miller's (1960) conclusion that large floods transport only a small proportion of the annual sediment load. However, in catchments where erosion processes such as landsliding dominate, and thresholds for erosion are higher, large magnitude, less frequent events are more important (see Kasai and Marutani, Nishiyama).

Impact of human disturbance on sedimentary cascades

Pronounced 'natural' variability in patterns and rates of sediment delivery is accentuated by differing degrees of human disturbance to landscapes, the sensitivity of different landscapes to change, and associated morphologic responses of channels following disturbance. A recurring issue for the management of catchment processes to mitigate sediment disasters is the need to discriminate between natural and human induced impacts.

Successful strategies for mitigation, recovery and restoration of catchments need to be developed in harmony with natural controls on landscape behaviour. This is difficult in countries where there is a long history of human occupation. However, even in countries like New Zealand, where there has only been a relatively short period of human settlement, the varying nature of sediment responses makes such discrimination difficult (Page et al.). Given the short timeframe with which humans view their environment, it is all too easy to underestimate the variability (magnitude and frequency) of natural processes. Nevertheless, the signature of human disturbance is so profound in many parts of Australia that specific types of deposit have been identified as Post-European Material (PEM) (see Crighton and Gore). In addition, valley floor incision has released extensive volumes of material in these landscapes, in the form of sediment slugs (sensu Nicholas et al., 1995; see Bartley et al., Fryirs and Brierley, Rutherfurd). To place the impacts of human disturbance into their broader context, paleoenvironmental reconstructions must be derived from geomorphic evidence and sedimentary records.

Knowledge of how human disturbance in a catchment affects sediment yield is in itself insufficient for management purposes. The catchment response to this disturbance will likely involve changes in source and deposition sites, for some sites the initiation of new processes and for others a change in process rate. Major changes in morphology and behaviour of streams and rivers can be expected. The new roles that different parts of the catchment play will lead to changes in the spatial and temporal variability of sediment transfer relationships (cf., Benda and Dunne, 1997; Kelsey et al., 1987).

Various forms of human disturbance to catchment-scale sediment budgets are demonstrated in the case studies in this book, including:

* Sediment accumulation in reservoirs (Shimizu and Araya)
* Geomorphic and sediment budget responses to engineered river morphology (e.g. straightening of a meandering reach through imposed cut-offs; Kuroki et al.)
* Responses to tin mining (Bartley et al.)
* Responses to catchment scale deforestation (Page et al.)
* Responses to forestry practice (Kasai and Marutani, Page et al.; Zieimer, Madej and Ozaki) and agricultural land use (Maita)
* Inadvertant geomorphic/sediment budget responses to clearance of riparian vegetation, drainage of swamps, removal of large woody debris, and excessive stocking rates (Bartley et al., Crighton and Gore, Fryirs and Brierley, Rutherfurd).

Timeframes for readjustment vary markedly in differing geo-systems, presenting starkly contrasting implications for land, water and river management.

Management Implications and Future Research Directions

As a consequence of the differing nature and rate of sediment transfer in landscapes, and the variability in human settlement patterns and associated land management practices, there has been pronounced variability in management responses to a range of sediment budget problems in different catchments around the Pacific Rim. Hence, while sediment retention dams are a prominent feature of much of the Japanese landscape, there are no similar sediment control structures placed in New Zealand channels for equivalent rates of sediment transfer (though this is not to deny the trapping efficiency of dams built for generation of hydro-electric power). Assessing the benefits of mitigation strategies is such a concern in some places that monitoring programs have been established to evaluate the effects of change. For example, numerous programs have been established to assess the impacts and consequences of forest management practices (e.g. Shimizu and Araya, Kasai and Marutani, Ziemer, Madej and Ozaki).

The diversity of factors that influence sediment movement at the catchment scale ensures that there are inherent dangers of spatial and temporal clumping in assessment of sediment budgets (cf., Walling and Webb, 1983). Broad-scale generalities can be dangerous, as the nature and rate of geomorphic processes may vary profoundly over differing spatial and temporal scales. Hence, while some generalities about 'tectonically active landscapes' may have broad relevance, landscape responses to disturbance and associated management implications may vary in regions of differing lithology, topography, vegetation cover, climate, etc. Regional-scale differences in environmental setting ensure that national-scale generalities have little direct value for management responses. Indeed, stark differences may be recorded in adjacent catchments (see Page et al., Fryirs and Brierley).

Sustainable land/water management practices and environmental outcomes will only be achieved when they are framed upon reliable interpretation of baseline data that record the changing nature of sediment sources over time. For example, catchment-scale sediment management programs must underlie efforts at river conservation and rehabilitation (see Sear et al., 1995). Rates of sediment input from slopes, and reach-based sensitivity to disturbance, have enormous implications for the residence times of (re)stored material along river courses (e.g. Nakamura et al., 1987; Olive and Rieger, 1986; Phillips, 1995; Trimble, 1983; Wasson, 1994; Wasson et al., 1996). These considerations, in turn, may have profound off-site consequences, with associated implications for geomorphic river recovery (see Brookes, 1992; Fryirs and Brierley, 2001; Simon, 1995). Hence, landscape responses to sediment storage and transfer must be assessed, interpreting magnitude-frequency relationships that underpin landscape change, and the profound variability that may be evident in the residence time of differing sediment storage features. Further research in these areas is critical if geomorphologists are to make a significant contribution to improve the ecological health of rivers, landscapes and catchments. While extensive geomorphic research has started to address these issues, to date our insights lack the critical quantitative and predictive edge that is required for various ecological and engineering responses and planning applications.

It is timely for geomorphological investigations to be more effectively integrated through modelling applications, moving our understanding of landscape forms and processes beyond field based case studies (recognising implicitly the need for various gaps to be filled) towards greater conceptual understanding of sediment transfer relationships in differing landscapes. Without this broader conceptual understanding, it is difficult to quantify and model landscape sensitivity to change and predict landscape responses to disturbance. Indeed, in several case studies reported in this book, a key management aspiration is the desire to predict future landscape changes and associated responses in terms of sediment budgets, providing insights into timeframes and mechanisms of (eco)system recovery and hence development of sustainable land use programs. Interpretation of landscape sensitivity to human disturbance, and potential off-site implications, are key components in catchment-framed analyses of sedimentary cascades. It is only with these insights in-hand that reliable predictions of likely future sediment budget relationships can be discerned, the potential for geomorphic recovery assessed, and appropriate management actions taken.

In some instances, problems associated with sediment movement are near insurmountable, as exemplified by agricultural areas impacted by lahars adjacent to Mount Pinatubo (Sakatani and Inoue) and accelerated sediment accumulation along valley floors following cyclones along the North East Cape of New Zealand (Page et al.). In contrast, depletion of alluvial sediment stores places key, but not insurmountable, constraints on river rehabilitation programs along many river courses in Australia (see Fryirs and Brierley).

Finally, sediment budget methodologies are also being applied to address internationally recognised problems such as greenhouse gas warming. In New Zealand, process understandings developed in the Waipaoa catchment sediment budget are being used to assess how soil erosion reduces the nation's ability to absorb rising levels of atmospheric COI (see Tate et al., 2000). Page et al. begin to extend the traditional source-to-sink concepts of terrestrial geomorphology, to understanding terrestrial and marine interactions, and the potential role they play in addressing global greenhouse gas and climate change issues.

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