# I Natural disturbance in desert river systems

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# Desert or dryland rivers of the world: an introduction

R. T. KINGSFORD AND J. R. THOMPSON

Rivers channel the world's rainfall into floodplains, lakes or groundwater basins, or out to sea. They provide habitats for diverse biota that often climax in floodplain wetlands, areas of incredible biodiversity. River flows are integral to many coastal and marine environments, processes and organisms (Gillanders & Kingsford, 2002). Their fresh water allows humans to penetrate and flourish in the most inhospitable parts of this planet. They are the arteries that define ecological landscapes and processes for many biota. Climate and the nature of land surfaces primarily govern the size, hydrology, geomorphology and ecology of rivers. For example, the Amazon River, which accounts for about 20% of the world's river flow, is a massive river system originating in areas of extremely high rainfall. Contrast this with rivers from the desert regions of the world (Fig. 1.1) where rainfall is less than 500 mm per year and is usually exceeded by evaporation. In these regions rivers often stop flowing for long periods, sometimes even years.

What makes desert rivers any different from other rivers or aquatic systems around the world? This book uses 'desert' and 'dryland' interchangeably to describe land areas and their rivers where there is less than 500 mm of annual rainfall: the arid and semi-arid

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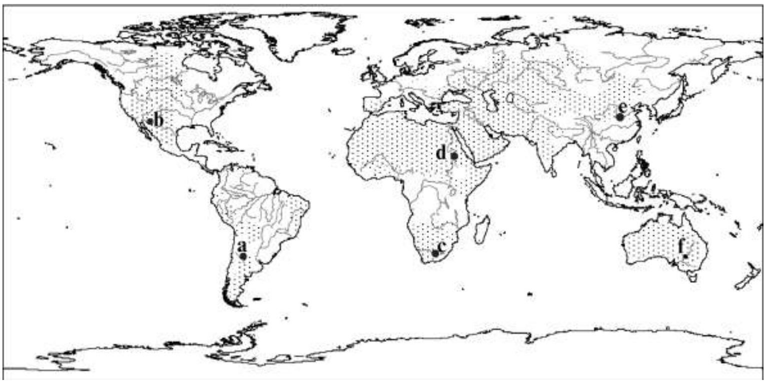



Figure 1.1. Desert or dryland regions of the world (dotted; annual rainfall < 500 mm), (after Middleton & Thomas, 1997) and some of their large rivers. Letters identify locations of six dryland rivers (dots are locations of gauges used), illustrating flow regimes (see Fig. 1.2): the San Juan River in South America (a), the Gila River in North America (b), the Orange River in South Africa (c), the Atbara River in northeast Africa (d), the Huanghe (Yellow River) in Asia (e) and the Darling River in Australia (f).

regions of the world (Fig. 1.1). This encompasses about 47% of the global land surface, including hyperarid, arid, semi-arid and dry humid regions (Table 1.1) (Middleton & Thomas, 1997). Why do we need a book about the ecology and management of these desert or dryland rivers? Intrinsic properties of scarcity and variability of these rivers and their associated floodplain habitats, combined with poor knowledge and increasing human pressures, demand attention. The story of desert or dryland rivers is one of changeable, changing and changed ecosystems, as humans progressively apply control.

Desert rivers do not have unique landforms (Nanson *et al.*, 2002) but their hydrology is much more variable than that of mesic rivers (McMahon *et al.*, 1992; Puckridge *et al.*, 1998; Peel *et al.*, 2001). We are only just beginning to understand the implications of such variability for the ecology of these rivers, the effects of river regulation and future management. Rivers in dry regions of the

Table 1.1. *Dry regions of the world, showing areas and percentages of each aridity zone in each global region of the world*

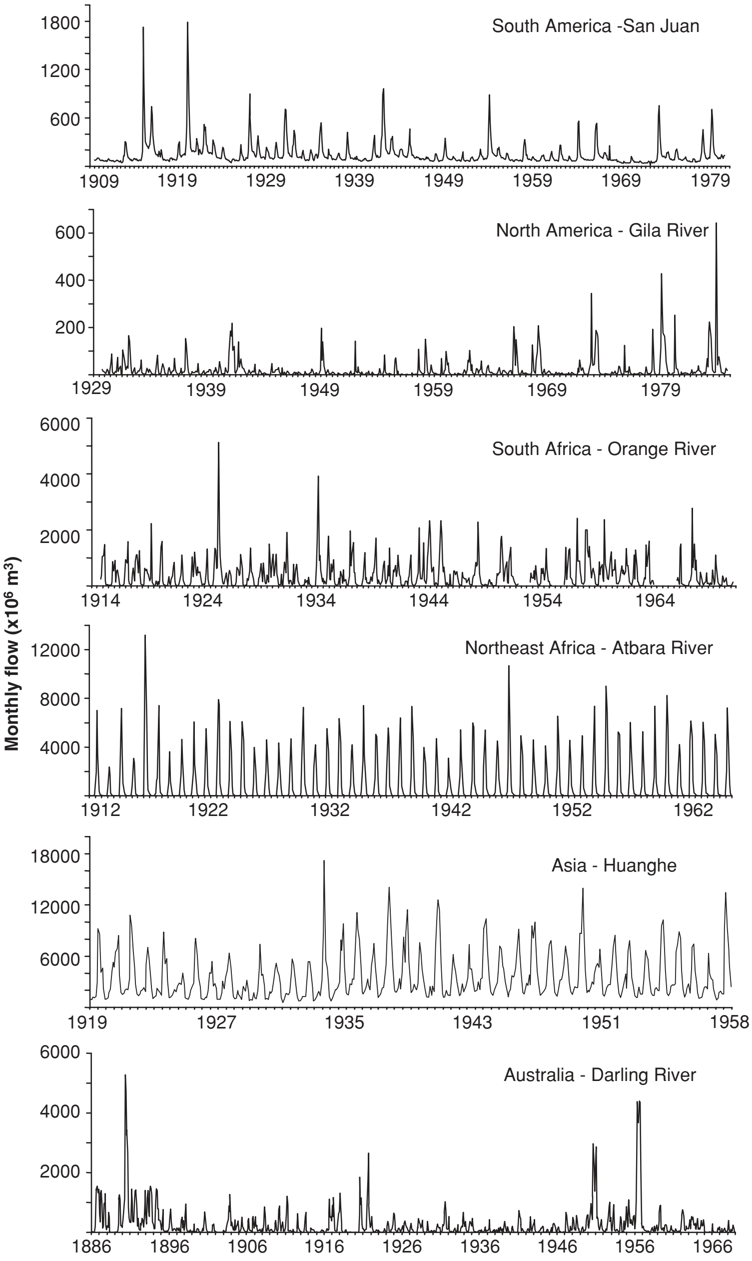
| Region | Area[a] | Dry humid | Semi-arid | Arid | Hyper-arid | Total |
|---|---|---|---|---|---|---|
| Africa | 2 965.6 | 9.1 | 17.3 | 16.9 | 22.7 | 66.0 |
| Asia | 4 256.0 | 8.3 | 16.3 | 14.7 | 6.5 | 45.8 |
| Australasia | 882.2 | 5.8 | 35.0 | 34.3 | 0 | 75.2 |
| Europe | 950.5 | 19.3 | 11.1 | 1.2 | 0 | 31.5 |
| North America | 2 190.9 | 10.6 | 19.1 | 3.7 | $<1$ | 33.6 |
| South America | 1 767.5 | 11.7 | 15.0 | 2.5 | 1.5 | 30.6 |
| World | 13 012.7 | 10.0 | 17.7 | 12.1 | 7.5 | 47.2 |

[a] Millions of hectares.
*Source:* after Middleton and Thomas (1997).

world are the poor cousins in the knowledge base of river and wetland ecology. Their ecology is probably the least known of our freshwater resources (Williams, 1988; Nanson *et al*., 2002), despite recent advances in understanding (see Bull & Kirkby, 2002), because relatively few people live in such inhospitable parts of the world. Scientific effort is often strongly biased towards humid regions, with most of our knowledge of aquatic ecology from temperate freshwater science (Ward *et al*., 2001). Even in a relatively affluent country such as Australia, where arid regions dominate (75% of the land area), freshwater scientific effort can be biased towards the mesic regions where most people live (Kingsford, 1995). Desert rivers and their ecology are often out of sight and out of mind, so it is important to consolidate our knowledge and provide a basic framework for ecological understanding of desert or dryland rivers.

## DESERT OR DRYLAND RIVERS OF THE WORLD

Almost 50% of the world's land surface is either arid or semi-arid (Middleton & Thomas, 1997), occupying most continents (Comín & Williams, 1994). Many thousands of streams and large rivers flow wholly or partly through such areas (Fig. 1.1). Rivers and their


Monthly flow (x10⁶ m³)
South America -San Juan
1800
1200
600
1909 1919 1929 1939 1949 1959 1969 1979
North America - Gila River
600
400
200
1929 1939 1949 1959 1969 1979
South Africa - Orange River
6000
4000
2000
1914 1924 1934 1944 1954 1964
Northeast Africa - Atbara River
12000
8000
4000
1912 1922 1932 1942 1952 1962
Asia - Huanghe
18000
12000
6000
1919 1927 1935 1943 1951 1958
Australia - Darling River
6000
4000
2000
1886 1896 1906 1916 1926 1936 1946 1956 1966

dependent ecosystems form a continuum of variability, seldom adequately captured by pigeonhole classifications. This variability is characteristically higher in dryland rivers. Rivers challenge us even more because their longitudinal dimensions seldom respect climatic regions; worse, for managers and policy makers, they do not respect jurisdictional or national borders (Postel, 1996; Kingsford *et al.*, 1998). Many large rivers that flow through desert regions (e.g. the Nile, Okavango and Murray) originate in mesic areas. This book adopts a broad definition of what constitutes a desert river because it is impossible to divorce a river from its catchment: desert rivers flow wholly or partly through desert or dryland regions of the world (annual rainfall $< 500$ mm).

Climate drives river flows and dependent ecological responses. Within desert regions rainfall is low and is often highly variable in both space and time (Peel *et al.*, 2001). Hydrology holds primacy in any treatment of rivers, their behaviour and their understanding. By way of introduction, we take the monthly flows of six unregulated desert rivers from different regions of the world: North America, South America, northeast Africa, South Africa, Asia and Australia (Fig. 1.2). Even a simple inspection of monthly flow regimes illustrates considerable differences among rivers from these different regions. Seasonal regularity, particularly in relation to wet and dry seasons in the tropics (Atbara River, northeast Africa) and snowmelt in temperate regions (Huanghe River, Asia) is translated into a clear seasonal signal in river flows (Fig. 1.2), which has considerable implications for ecology and management. Interannual variability is relatively small compared with that of rivers in other desert regions of the world such as South Africa, North and South America and Australia (Fig. 1.2). In these regions annual variability in the timing and volume of flows is also high. Some dryland rivers have periods of no flow or low flow. In some, such as the

Figure 1.2. (opposite) Monthly flow regimes for six desert or dryland rivers from around the world (see Fig. 1.1 for locations; dots indicate locations of gauges used for analysis). Rivers were chosen on the basis of the availability of at least 30 years of data for periods where there was relatively little river regulation (data provided courtesy M. Peel) (Peel *et al.*, 2001; McMahon *et al.*, 1992).

Atbara River in Northeast Africa (Fig. 1.2), these periods coincide with the marked dry season and their timing and duration are relatively uniform. Others, such as Australia's Darling River and the Gila River of North America (Fig. 1.2), exhibit less predictable periods of low or no flow. Such regions generally have highly stochastic rainfall that results in extremely variable river flows, a pattern particularly well known for Australian and South African rivers (McMahon *et al*., 1992; Puckridge *et al*., 1998; Peel *et al*., 2001; Nanson *et al*., 2002). Chapter 2 of this book extends this introduction into river ecology by examining in considerably more detail some of the differences in the hydrology of desert rivers and their implications for river ecology and water resource development.

It follows that hydrological disturbance patterns exert a dominant influence on the ecology of desert rivers, through the drying and flooding of river habitats: channels, waterholes, floodplains and estuaries. Hydrology affects geomorphological processes of rivers, which in turn drive the distribution of dependent vegetation (Chapter 3, this volume). The next section of the book has a series of chapters that examine ecological responses to variable flows in desert rivers. This begins with food webs and productivity (Chapter 4) and moves to higher levels of biota: plants (Chapter 5), invertebrates (Chapter 6) and vertebrates (Chapter 7). A new force, almost as important as climate, now governs the hydrology and ecology of many rivers: human control.

The human responses to water scarcity around the world are driving major changes to dryland rivers. Part II of this book concentrates on how humans have altered the behaviour of dryland rivers, affecting their ecology. Despite our lack of knowledge, we are busily exploiting dryland rivers, wreaking immeasurable ecological damage (Lemly *et al*., 2000; Gillanders & Kingsford, 2002). Are we changing these unique systems forever? This part of the book begins with an examination of how we change desert river flows and the impact these changes have had on some of the more spectacular and biodiverse habitats in the world (Chapter 8). The next chapter shows the long-lasting and extensive hydrological and ecological effects of even relatively minor river regulatory structures, such as weirs, on the Lower River Murray (Chapter 9). Deserts are naturally salty places, but human land and river management is increasing the salinity of desert rivers with severe ecological consequences (Chapter 10). Expanding human populations represent the greatest pressure on the world's water resources (Postel, 2000), at their most extreme in desert regions (Chapter 11). Finally, a synthesis chapter (Chapter 12) examines the competing demands of the ecology of desert rivers and their changeable nature against our ever-increasing needs for water, imposing simplicity on incredibly complex ecosystems. Hopefully, this book will encourage an interest in the magnificent systems that are desert rivers, will raise awareness of the challenges that they face, and will in turn promote their future conservation.

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# Flow variability in large unregulated dryland rivers

W. J. YOUNG AND R. T. KINGSFORD

## INTRODUCTION

The presence or absence of water defines much of the ecology of semi-arid and arid landscapes (Stafford Smith & Morton, 1990; Chapter 7, this volume), and rivers and their flows mediate much of the ecological variability (Walker *et al.*, 1995). Dryland rivers drain or traverse the hyperarid, arid and semi-arid regions of the world where mean annual rainfall is less than 500 mm and where mean annual evaporation is equivalent to at least 95% of the rainfall and is often even higher (Meigs, 1953; Chapter 1, this volume); these are the 'B' category climates in the Köppen climate classification (Köppen & Geiger, 1930). Dryland regions represent over half of the world's land area (Thomas, 1989) and are drained by many of the world's major rivers (Kingsford, 2000a; Chapter 1, this volume).

Although dryland regions are widespread in distribution, their harsh climates and limited water resources have often meant that they support comparatively small human populations, and thus dryland rivers are generally less developed than their humid counterparts. For the same reasons, far fewer scientific studies have occurred in dryland regions than in humid regions (Williams, 1988; Kingsford, 1995). As the global population and the associated food and energy demands grow

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