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Hydrology and Ecology of Intermittent Stream and Dry Wash Ecosystems

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Abstract

Ephemeral (dry washes) and intermittent streams make up approximately 59% of all streams in the U.S. (excluding Alaska), and over 81% in the arid and semi-arid Southwest (Arizona, New Mexico, Nevada, Utah, Colorado and California) according to the National Hydrography Dataset. They are often the headwaters or major tributaries of most perennial streams in the Southwest, and make up 94% of stream miles in Arizona. Given their vast extent, ephemeral and intermittent streams are crucial to the overall health of a watershed, providing a wide array of functions including forage, cover, nesting, and movement corridors for wildlife. Because of the relatively higher moisture content in dryland streams, vegetation and wildlife abundance and diversity is higher than in the surrounding uplands. Ephemeral and intermittent streams provide the same hydrologic functions as perennial streams by moving water, nutrients, and sediment through the watershed. When functioning properly, dryland streams provide many of the same services as perennial riparian-wetland areas, such as landscape hydrologic connections; stream energy dissipation during high-water flows that reduces erosion and improves water quality; surface and subsurface water storage and exchange; groundwater recharge and discharge; sediment transport, storage, and deposition aiding in floodplain maintenance and development; nutrient cycling; wildlife habitat and movement/migration; support for vegetation communities that help stabilize stream banks and provide wildlife services; and water supply and water-quality filtering. Ecologically sustainable land and wildlife management requires a landscape or watershed-scale approach to ecosystem protection, and would be meaningless and ineffective if these supporting waterways are significantly degraded.

Introduction

Intermittent and ephemeral streams, or dry washes, are found in the arid and semi-arid regions of the Earth that are commonly referred to as “drylands”. Nearly one-third of the Earth’s land surfaces are classified as arid or semi-arid (Whitford, 2002). These lands are characterized by low and highly variable annual precipitation, where annual evapotranspiration exceeds precipitation. It is precisely because of these dry conditions, which result in great contrast between the moist riparian areas and adjacent dry upland communities, that these streams are so important. The US EPA, using the National Hydrography Dataset (NHD; USGS, 2006), has estimated that 59% of U.S. streams (excluding Alaska) are ephemeral or intermittent (U.S. EPA, 2005). Nearly 81% of all streams in the six Southwestern states (Arizona, New Mexico, Nevada, Utah, Colorado and California) are ephemeral or intermittent (calculated from the National Hydrography Dataset, http://nhd.usgs.gov/).

Ephemeral and intermittent streams are often the headwaters or major tributaries of most perennial streams in the arid and semi-arid Southwest. When functioning properly, these dryland streams provide many of the same services as perennial riparian-wetland areas, such as landscape hydrologic connections; stream energy dissipation during high-water flows that reduces erosion and improves water quality; surface and subsurface water storage and exchange; groundwater recharge and discharge; sediment transport, storage, and deposition aiding in floodplain maintenance and development; nutrient transport and cycling; wildlife habitat and movement/migration; support for vegetation communities that help stabilize stream banks and provide wildlife services; and water supply and water-quality filtering (USFWS, 1993; BLM, 1998).

These functions depend on the balance and interactions between water, vegetation, soil, and geology. Sustainability and resilience to disturbance are also important characteristics in dryland stream systems when addressing ecologically sustainable land management. Because of the lack of water, dryland ecosystems do not recover quickly from disturbance. The disturbance or loss of ephemeral and intermittent streams has dramatic physical, biological, and chemical impacts which are evident from the uplands to the riparian areas or stream courses of the watershed. The amount of precipitation that immediately runs off the land surface, and infiltrates into the soil to either be used for plant growth or to recharge ground water, is dependent on this critical interface (Barnett et al., 2002). Ecologically sustainable land management requires a landscape or watershed-scale approach to ecosystem protection, and would be meaningless and ineffective if these supporting waterways are significantly degraded.

Hydrologic Considerations

A stream can be defined as a natural body of flowing water, either on the surface or below. It can be perennial, intermittent or ephemeral. Ephemeral streams (or dry washes), and intermittent streams are the chief characteristic of drylands. An *ephemeral stream* may be defined as a stream or portion of a stream which flows briefly in direct response to precipitation in the immediate vicinity, and whose channel is at all times above the water table elevation. An *intermittent stream* is one where portions of the stream flow continuously only at certain times of the year, for example when it receives water from a spring or from a surface source, such as melting snow (i.e. seasonal).

These two stream types differ greatly from a *perennial stream*, which is defined as a stream that flows on the surface continuously throughout the year, and is considered permanent. Baseflow of a perennial stream is maintained by groundwater discharge to the stream bed, and the water-table elevation adjacent to the stream is typically greater than the surface-water elevation within the stream.

In addition to their chief attribute of lacking perennial flow, ephemeral and intermittent streams in drylands also experience extreme variations in flood regime, rarely reaching process-form equilibrium due to irregular flows. They have high rates of sediment transport, and show a relationship between flood magnitude and duration with the size of the watershed (Reid and Frostick, 1989; North, 2005). Biophysical characteristics such as channel geometry, morphology, and plant-community type are dependent on where an ephemeral or intermittent channel originates. Steep watersheds will have different features, such as alluvial fans and bajadas, than watersheds of gently rolling hills (Whitford, 2002).

Most streamflow events in a good portion of the Sonoran and Chihuahuan Deserts occur during the summer monsoon (July through September) from high-intensity, short-duration rainfall events which typically occur as air-mass thunderstorms resulting from convective heating of moisture-laden air masses (Gochis et al., 2006). Streamflow may last only minutes or hours, or may persist for days or weeks depending on the climatic regime and the nature of the watershed contributing area. Flash floods may occur any time of the year after the watershed has had enough precipitation to generate runoff. Long-duration, lower-intensity events are typical of cool-season precipitation caused by frontal systems originating in the eastern North Pacific Ocean (Hereford et al., 2003). It is relatively rare for ephemeral channels to have significant streamflow from low-intensity cool-season precipitation. Less frequently (approximately three to five percent of the annual rainfall in southern Arizona, on average), runoff and streamflow occurs from the remnants of hurricanes and tropical depressions which track north from lower latitudes. The influence of both the summer monsoon and increases in precipitation from tropical depressions decreases as one moves north.

The high degree of spatial and temporal variability in hydrologic processes and the resulting erosion and sedimentation processes in arid and semi-arid regions as compared to humid regions means that these characteristics cannot be reliably predicted by extrapolation from humid regions (Scott, 2006; McMahon, 1979). Due to sparse vegetation cover and poorly developed soils with little organic matter, it is typical for desert environments to produce more runoff and erosion per unit area than in temperate regions for a given intensity of rainfall (Thornes, 1994). Graf (1988) reported that for a humid region in Pennsylvania, the 50-year return flood event is roughly 2.5 times the mean annual flow, whereas the 50-year return flow for the Gila River in Arizona is about 280 times the mean annual flow. Of the 12 largest floods ever measured in the United States, all occurred in semi-arid to arid regions, and 10 occurred in regions with less than 400 mm (16 in.) of rainfall (Costa, 1987).

Other aspects of dryland floods are highly distinctive. For example, flow hydraulics and roughness coefficients are strongly influenced by the vegetation that commonly grows on the normally dry channel beds to exploit moisture contained in subsurface sediments. Low annual precipitation inevitably means low annual runoff, with interannual variability of runoff increasing as annual totals decrease (McMahon, 1979; Rodier, 1985). In North American arid lands, for instance, the variability of mean annual runoff is about double that for the continental areas as a whole (McMahon, 1979). In addition, given the spatially variable patterns of precipitation and runoff in drylands, for any given watershed size there is a large range in annual runoff totals (Reid and Frostick, 1997). Some studies have noted that a large portion of our watersheds in the western states (up to 90% in Arizona, for example) produce less than 12.7 mm (0.5 in.) runoff per year, but the vast extent of these dryland watersheds makes their total runoff production significant, and their proper management important (Renard, 1970). Figure 1 shows a comparison of the average annual precipitation for the Western U.S. for 1961-1990, and the locations of ephemeral/intermittent and perennial streams from the NHD dataset. Note the correlation between locations with higher average annual rainfall amounts and locations with perennial stream flow.

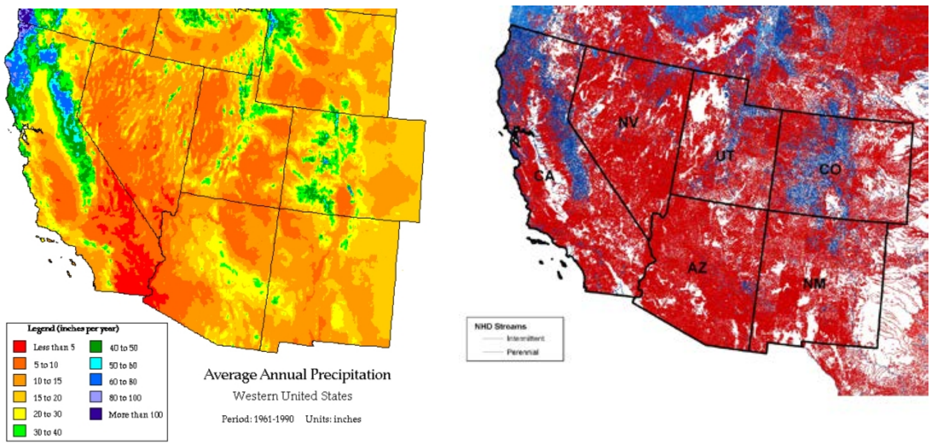

Figure 1. Comparison of average annual precipitation, 1961-1990 (left) with locations of ephemeral/intermittent (red) and perennial (blue) streams (right). (Western Regional Climate Center, http://www.wrcc.dri.edu/precip.html, and National Hydrography Dataset (NHD), http://nhd.usgs.gov/. Additional information on the NHD is available from their Technical Document "Concepts and Contents", http://nhd.usgs.gov/chapter1/chp1_data_users_guide.pdf).

In a spatial as well as a temporal sense, floods in dryland rivers exhibit some unique characteristics. Regardless of the source of floodwaters, flows in dryland rivers are generally influent, or subject to downstream volume decreases. These decreasing flow volumes principally are due to transmission losses resulting from infiltration of floodwaters into the unconsolidated alluvium forming channel boundaries, with further losses resulting from overbank flooding and evaporation of floodwaters (Babcock and Cushing, 1942; Keppel and Renard, 1962; Sharp and Saxton, 1962; Lane, 1983; Goodrich et al., 1997). Downstream volume decreases are sometimes negligible along small alluvial rivers or bedrock rivers, but for larger alluvial rivers they can be important, with many flows failing to travel the full length of the channel. Hence, in the absence of appreciable tributary inflows in the lower parts of the watershed, transmission losses produce significant downstream decrease in total flow volume, flood peak, and flow frequencies (Keppel and Renard, 1962; Lane, 1983; Knighton and Nanson, 1997; Goodrich et al., 1997).

An example of transmission losses within the USDA-ARS Walnut Gulch Experimental Watershed near Tombstone, Arizona is presented in Figure 2. The August 27, 1982 storm was isolated in subwatershed 6 on the upper 95 km^2 of the watershed (and not all of that precipitation produced runoff). The runoff measured at the nearest downstream flume, Flume 6, was 246,000 m^3 with a peak discharge of 107 m^3s^{-1}. Runoff traversing 10.86 km of dry streambed between Flume 6 and Flume 1 experienced significant infiltration losses. Total peak discharge was reduced by nearly half to 52 m^3s^{-1}, and 90,800 m^3 of water was absorbed in the channel alluvium.

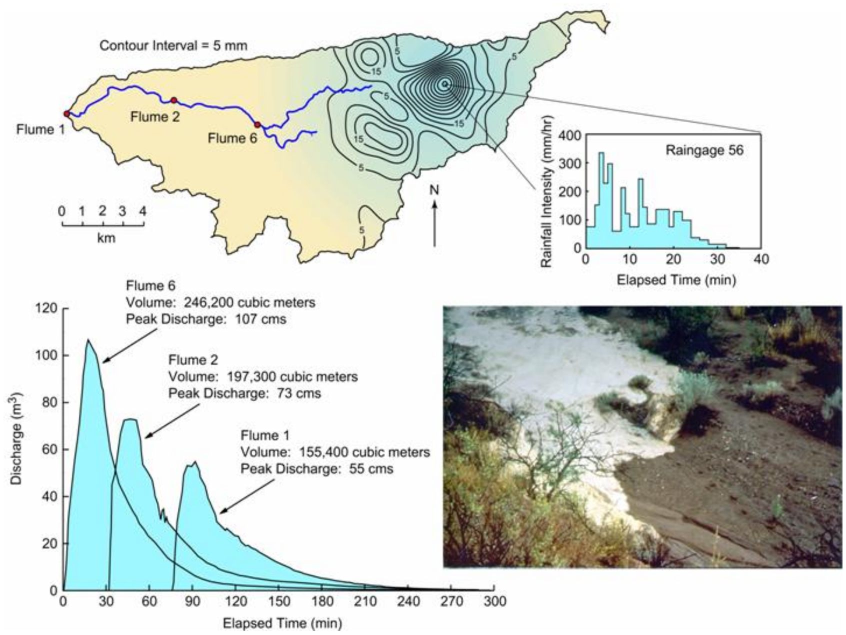

Figure 2. Rainfall-runoff event of August 27, 1982 illustrating ephemeral channel transmission losses and peak flow decreases as measured within the USDA-ARS Walnut Gulch Experimental Watershed near Tombstone, Arizona

As a result of decreased flow rate in the downstream direction, more silts and fines are deposited in the channel which can be advantageous to biotic communities. A study of ephemeral rivers in the Namib Desert (Jacobson et al., 2000) found that "Organic carbon, nitrogen and phosphorous were correlated with silt content, and silt deposition patterns influence patters of moisture availability and plant rooting, creating and maintaining micro-habitats for various organisms." Jacobson concluded that "…alluviation patterns associated with the hydrologic regime strongly influence the structure, productivity, and spatial distribution of biotic communities in ephemeral river ecosystems."

The importance of locally recharged monsoon water derived from ephemeral channel runoff for maintaining flow in the main stem of the San Pedro River was demonstrated by Baillie et al. (2007). Using a suite of geochemical tracers and a two end-member mixing model they found that locally recharged monsoon floodwaters is one of the dominant water sources in the main stem of the San Pedro River, with these waters comprising 60 to 85% of riparian groundwater in losing reaches of the main stem and 10 to 40% in gaining reaches. Baseflows also contained a significant component of monsoon flood water: 80% at the upstream segment, and decreasing to 55% after several gaining reaches (Baillie et al., 2007).

Although ephemeral or intermittent streams do not contain water at all times, they still perform the major functions of a stream: the transportation of water, nutrients, and sediment. Unlike perennial streams that continuously move sediment through the watershed, sediment movement in ephemeral or intermittent channels occurs as a pulse through the system in response to runoff generated by the short duration, high intensity thunderstorms that result in flash floods. Sediment is also moved from the uplands and hillslopes into the channels from overland flow. The effect is a pulsing style of sediment movement that doesn't always reach the watershed outlet, but is instead remobilized during the next flow and redistributed within the watershed's channel network.

The relative importance of many fluvial processes in arid regions, especially the magnitude and frequency of their operation, differs considerably from more humid regions (Graf, 1988; Thornes, 1994; Bull and Kirkby, 2002). As a result, channel forms also differ considerably from humid regions where the bulk of observations have been made. Although one of the most universally recognized traits of dryland ephemeral channels is their enormous variability in form, a number of broad generalizations have been used to characterize them: 1) They are often closely spaced, resulting in a high drainage density; 2) They have high width-to-depth ratios, are more likely to be braided, and have low sinuosity relative to their humid counterparts; and 3) Bed topography is generally subdued, and often near horizontal and planar.

Ecological Considerations

Miller (2005: p. 18) stated that “the most important functions in dryland ecosystems are those that control the retention of water and nutrient resources because productivity and diversity cannot be sustained in systems that fail to retain these resources”. Vegetation in dryland channels plays a key role in resource retention by protecting soils from wind and water erosion, slowing flood velocity, and moderating temperatures.

Vegetation in drylands is largely controlled by the availability of water, with flood disturbance and edaphic conditions further shaping plant distribution patterns. By providing channel and stream bank roughness, vegetation can influence flow velocities, flow depths, bank and floodplain erosion, and sediment transport and deposition, and can be a major factor contributing both to channel stability and to channel instability. In ephemeral or intermittent channels, vegetation may establish on sand bars in channel beds, and subsequently initiate the formation of various depositional features such as small current shadows, bars, benches, ridges or islands (Tooth and Nanson, 2000). Spatially extensive assemblages of any plant species have the potential to alter geomorphology and geomorphic processes through bioturbation, alteration of nutrient or fire cycles, and patterns of succession (Lovich, 1996). Riparian vegetation also influences biogeochemical cycles and water/energy balance, and provides food and cover for wildlife. Changes in the abundance or composition of the plant community thus affect an array of ecosystem functions and processes.

During seasonal dry periods, plant species diversity levels along ephemeral streams typically are low, with values much lower than along perennial streams and also often lower than in adjacent uplands (Leitner, 1987). During seasonal wet periods, however, diversity levels along some ephemeral streams can equal or exceed that of perennial streams (Stromberg, unpublished data). Water from rainfall and flood flows can trigger a pulse of germination of annual and perennial plant species along the ephemeral stream beds. Because the dry-season cover of the woody vegetation is low, and cover of bare soil is fairly high, the seasonal resource pulses can result in very high diversity levels in comparison to that of the more densely-vegetated perennial streams. Many of the plant species that establish along ephemeral streams during water pulses arise from soil seed banks. Dryland rivers, including ephemeral reaches of spatially intermittent rivers, maintain large and diverse soil seed banks. Rivers that are ephemeral over their entire length (i.e., autogenic desert rivers) have sparser riparian seed banks than do dry reaches of rivers with headwaters in humid mountains (i.e. allogenic desert rivers) (Stromberg, unpublished data).

Diversity varies with seasonal rain and flood patterns, and also varies on longer temporal scales. During periods of sustained runoff, ephemeral washes can support a high density and diversity of wetland (hydroriparian) plant species (Stromberg, unpublished data). These “ephemeral wetland” communities develop with a recurrence interval of perhaps once per decade or more, depending on the flow regime of the particular river.

The biogeochemical features of a riverine system include cycling of elements and compounds, removal of imported elements and compounds, particulate detention, and organic matter transport. These features in ephemeral and intermittent streams are important for determining water quality, sediment deposition, nutrient availability, and biotic functions in both low order streams and downstream perennial waters. Biogeochemical features are affected directly and indirectly by land-use and land-cover change. Hydrologic modifications such as direct alteration of flow regime and hydrologic flow paths, and indirect alterations such as increased impervious cover in contributing areas of the watershed can cause biogeochemical changes. Elimination of the surface water - ground water connection, or disruption of the connection between a stream and its watershed by large scale changes such as urban and suburban development also influence biogeochemical functions (Grimm et. al., 2004).

The variable nature of rainfall in arid environments affects the biogeochemical features of low order streams. These systems are driven by pulse inputs of water, sediment, organic matter, and other materials during rain events. If the rainfall is not sufficient to transport material downstream into larger rivers, the material is stored and processed in the low order streams. This processed material can be transported downstream during large, infrequent storm events. Thus, ephemeral and intermittent streams in arid environments are important for storage and transformation of material and the eventual transport of material downstream to larger rivers.

Various studies have indicated that the periodic flooding of ephemeral or intermittent channels has a strong influence on biogeochemistry by providing a connection between the floodplain and other landscape elements (Valett, et al., 2005). For example, one study on the San Pedro River in Arizona found that approximately 98% of nutrients come into the river during the summer monsoon thunderstorms from ephemeral tributaries, and that almost 60% of that input occurs as a flux of particulate matter (Koch et. al, 2006). Organic material brought into and stored in small low-order streams, can be broken down and transformed into forms more readily available for use by biota in larger perennial streams (Richardson et al. 2005). This was also confirmed by Brooks and Lemon (2007) who concluded that in the San Pedro River, high concentrations of organic matter, and especially high concentrations of nitrogen occurred with the inflow of monsoon runoff from lateral ephemeral tributaries.

Wildlife Concerns

Land management for wildlife has traditionally focused on perennial stream systems and their associated riparian areas, with little attention paid to the importance of tributaries to these perennial streams, which are often ephemeral or intermittent. Because of the concentration of moisture and lush vegetation in ephemeral stream channels in comparison to the surrounding uplands, these areas provide the primary habitat, predator protection, nesting sites, shade, and food sources for wildlife in drylands. The micro-climates created in and around ephemeral streams are utilized extensively by wildlife, and especially by those species that cannot avoid the harsh desert environment by moving to a more favorable climate. Frequently, these streams may retain the only available water in the area in temporary or perennial pools.

Although the distribution and composition of wildlife species that occur in or utilize ephemeral or intermittent stream systems is not completely understood, the list of species known to be associated with these habitats is long. For example, larger mammals such as deer or bear use riparian vegetation as travel corridors, and smaller mammals such as squirrels, raccoons, or rabbits use it for foraging. Migrating song birds use ephemeral stream corridors extensively as they move through drylands because they contain the densest vegetation, and therefore the best cover and food sources. Reptiles and amphibians rely heavily on dry washes for breeding, and the majority of benthic macroinvertebrates occur in ephemeral and intermittent streams (NWF, 2007).

Most desert species have developed adaptations to the water-limited conditions of drylands, and are habitat and niche specific, allowing them to survive under adverse environmental conditions (Ward, 1973; Louw and Seely, 1982; Williams, 2006). Ward (1973) noted that the life cycles of these species are triggered by specific temperature and/or water conditions, and they may remain dormant or aestivate during unfavorable or stress periods.

Most studies of riparian habitat values have focused on aquatic or avian species. Riparian areas are critical in providing migration stopover sites, and therefore affect the breeding success of northern bird populations (Skagen et al., 1998). Avian species are highly dependent on riparian corridors, whether continuous, discontinuous, ephemeral or perennial. Skagen et al. (1995) looked at the geography of spring bird migration through riparian habitats in the southwest and found that all riparian habitat types were used to some degree. "Riparian habitats" was defined as vegetation communities in association with perennial, ephemeral and intermittent surface and subsurface waters. Skagen et al. (1998) compared the use by migrating birds of riparian corridors versus isolated oases (riverine vegetation isolated from similar vegetation patches) in the San Pedro River of Southern Arizona, and found that "Small, isolated oases hosted more avian species than the corridor sites, and the relative abundance of most migrating birds did not differ between sites relative to size-connectivity." They concluded that the protection of both the small patches and the more extensive riparian corridors is imperative, given the overall habitat limitation in western landscapes.

Although ephemeral streams will only support fish if permanent pools are present, they can still indirectly support fish populations. Cummins and Wilzbach (2005) noted that ephemeral and intermittent streams are important suppliers of invertebrates and detritus to permanently flowing, receiving streams that support juvenile salmonids. Del Rosario and Resh (2000) compared invertebrates in the hyporheic zone in an intermittent and a perennial stream in northern California, and found that intermittent streams had lower densities, similar richness, but higher species diversity than perennial streams.

All amphibians spend at least part of their life cycle in water, sometimes only for breeding. Most reptiles are found near water, although they are not as dependent on it as amphibians (Ohmart and Zisner, 1993). Rosen and Lowe (1996) in their study of herpetofauna at Organ Pipe Cactus National Monument, Arizona, noted that anurans (toads and frogs) are closely tied to permanent or temporary surface water that is long-lasting enough to allow their eggs to hatch and produce tadpoles. As little as 10 days may be required for the desert spadefoot (*Scaphiopus couchi*), with a longer period required for the true toads (genus *Bufo*). They found that anurans bred successfully in temporary pools in major washes and ephemeral springs, and some species of snakes and lizards preferred xeroriparian habitat because of the dense cover. In addition, during drought peaks, almost every other (non-riparian dependent) snake species used the xeroriparian habitat as a refugia against drought periods, although those that normally used that habitat type had a higher survival rate. Xeroriparian habitat was preferred by certain snake species due to higher prey abundance, higher relative humidity, and the presence of denser vegetation for cover. They also found that lizard species were most abundant in mesquite bosque and xeroriparian habitats (see Figure 3).

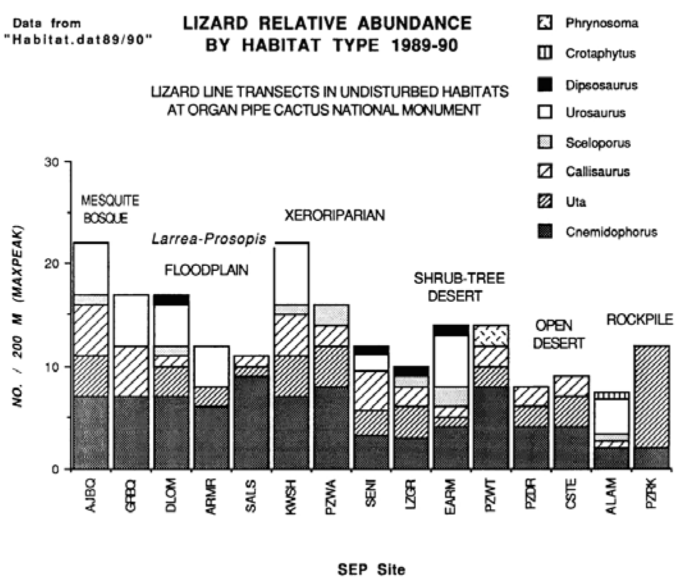

Figure 3. Lizard abundance by habitat type at Organ Pipe Cactus National Monument, (1989-1990), Arizona. Maxpeak refers to maximum peak value observed for all runs of transects within a habitat type at a site. SEP is the Sensitive Ecosystems Program (from Rosen and Lowe, 1996).

A wide variety of mammals inhabits the arid and semiarid southwest, and can utilize temporary and permanent pools found in ephemeral or intermittent streams. Most have adapted to the harsh conditions and lack of water in one or more of the following ways: heat evasion (daily or seasonal estivation, diurnal or nocturnal behavior), water conservation, water storage, dehydration tolerance, heat tolerance, and heat dissipation (open-mouthed gaping, or long appendages such as long ears). Many mammals burrow under ground during the hottest part of the day to avoid the heat and increase water conservation. Others, such as many small rodents, have adapted so they do not need free water at all.

Conclusions and Recommendations

There seems to be little doubt that there are gaps in our understanding of arid and semiarid ecological and hydrological processes that hamper efforts to quantify the natural or modified characteristics of these ecosystems. However, given their large extent, ephemeral or intermittent stream systems are important sources of sediment, water, nutrients, and organic matter for downstream systems and provide habitat for many species (Gomi et al., 2002), and their inclusion is important for watershed-based assessments (Gandolfi and Bischetti, 1997; Miller et al., 1999).

The variability of the hydrological regime is the key determinant of both plant community structure in time and space and the types of plants and wildlife present in dryland streams. Overall, changes to natural hydrological regimes in desert rivers reduce temporal and spatial heterogeneity of plant habitats, resulting in the loss of biodiversity and homogenization of plant community composition and structure. Given the ecological importance of plant communities in desert rivers (e.g. for channel bank stabilization, wildlife habitat), there may be significant secondary impact. There is some evidence to suggest that restoration of natural hydrological regimes in ephemeral streams may be sufficient to partly reverse such deleterious changes in plant communities (see for example, Stromberg, 2001).

The management of arid and semi-arid lands drained by ephemeral channels has a direct impact on the hydrology and geomorphology of the drainage network, in addition to wildlife habitat. Indeed ephemeral streams are much more sensitive to climate or anthropogenic disturbance than perennial streams (Bull, 1997). Anthropogenic disturbances include livestock grazing, land clearing, mining, timber harvesting, groundwater withdrawal, stream flow diversion, channelization, urbanization, agriculture, roads and road construction, off-road vehicle use, camping, hiking, and vegetation conversion. Biological stressors include habitat loss, alteration, and degradation from decline in water quality and changes in channel and flow characteristics (Pima County, 2000). For example, impervious surfaces in urban areas increase the frequency and magnitude of flooding. Storm sewers and lined drainages increase the rate at which these waters are delivered to the channel network, and thus further increase peak flows and erosion. Improperly constructed and maintained roads, especially dirt roads, can cause hill slope drainage alterations, baseflow alterations, and precipitation-runoff relationship alterations, resulting in erosion and sedimentation into the streams (USDA, 2002). The primary geomorphic consequence of these hydrologic changes is the erosional entrenchment of adjacent channels and associated transportation of the excavated sediment further downstream, causing a significant increase in sediment load, which may partly explain why most TMDLs in the Southwest are written for sediment. In addition as streams become entrenched, the floodplains can transform into dry terraces, causing formerly rich biological communities to become hydrologically disconnected from ephemeral streamflow. Additionally, as channels become narrower and unconsolidated alluvial bed material is removed, there is less capacity to absorb passing flows. Given the importance of transmission losses to regional aquifer recharge, long-term negative impacts to groundwater supplies are likely if these flows are not absorbed.

Stream channel characteristics are based on upland watershed and channel conditions. Physical characteristics such as the hydrology of the system drive biological values. Therefore, in order to protect critical riparian habitat, a watershed-based approach to land management must be taken, involving all stakeholders and applying best management practices to control runoff and erosion. Effective management of arid and semi-arid environments requires awareness of the interdependencies of hydrologic, biogeochemical and ecological processes, and collaboration between ecologists and hydrologists. Newman et al. (2006) suggests establishing a monitoring network in a water-limited environment to facilitate this collaboration, from the experimental design phase, through interpretation and modeling.

Much still needs to be learned about the ecological and hydrological interactions on ephemeral and intermittent streams due to variability and the often highly episodic occurrence of extreme events in these systems (e.g. sediment storage and flushing over decadal time scales). There are unique challenges for work on these desert rivers. Sometimes the environments are inhospitable, but arguably the greatest challenge is trying to use short-term projects to understand dryland rivers whose variable behavior sometimes demands years of data more than is needed on a mesic river. As noted, ephemeral and intermittent streams constitute the vast majority of drainage ways in the southwest and they play an integral role in overall watershed function. Future research is needed for both the long-term monitoring of these systems over a range of conditions, and on developing modeling tools that can be applied to large temporal and spatial scales.

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