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THREATS TO RIPARIAN ECOSYSTEMS IN WESTERN NORTH AMERICA: AN ANALYSIS OF EXISTING LITERATURE[1]

Boris Poff, Karen A. Koestner, Daniel G. Neary, and Victoria Henderson[2]

ABSTRACT: A total of 453 journal articles, reports, books, and book chapters addressing threats to riparian ecosystems in western North America were analyzed to identify, quantify, and qualify the major threats to these ecosystems as represented in the existing literature. Publications were identified either as research, policy, literature review, historical comparison, or management papers. All papers were evaluated based on year of publication, area of interest, and type(s) of threats addressed. Research papers, however, were assessed in more depth. The publications ranged from the 1930s to 2010 and addressed the following threats: dams, pollution (point and nonpoint), grazing, land use change, timber harvesting, water diversion, road construction, recreation, mining, groundwater pumping, invasive species, climate change, salinity, fire, insect and diseases, woody encroachment, watershed degradation, elimination of native vegetation, beavers, fire suppression, and fuel management. While the types of threats vary on spatial and temporal scales, some persist through decades in western North America. This analysis shows that grazing has been perceived as a dominant threat since the 1980s, but has been diminishing in the past decade, while invasive species, dams and, in recent years, climate change are increasingly represented in the literature as threats to riparian ecosystems in western North America.

(KEY TERMS: environmental impacts; riparian ecology; sustainability; water policy.)

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INTRODUCTION

Riparian ecosystems provide essential ecological functions, especially in western North America. While western riparian ecosystems occupy <2% of the total land area (Svejcar, 1997), they provide habitat for about one-third of the plant species. In the arid Southwest about 60% of all vertebrate species (Omhart and Anderson, 1982) and 70% of all threatened and endangered species are riparian obligates (Johnson, 1989). These ecosystems are not only unique because they have high species diversity and densities as well as high productivity, but they also allow for continuous interactions to occur between riparian, aquatic, and upland terrestrial ecosystems through exchanges of energy, nutrients, and species (Johnson and McCormick, 1978). Riparian ecosystems are systems with a high water table because of proximity to an aquatic ecosystem or subsurface

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[2]Respectively, Hydrologist (Poff), Bureau of Land Management, Southern Nevada District Office, 4701 North Torrey Pines, Las Vegas, Nevada 89130; and Hydrologic Research Technician, Science Team Leader, Biological Technician (Koestner, Neary, Henderson), Rocky Mountain Research Station, USDA Forest Service, Flagstaff, Arizona 86001 (E-Mail/Poff: bpoff@blm.gov).

water and have distinct vegetation and soil characteristics. Aridity, topographic relief, and presence of depositional soils most strongly influence the extent of high water tables and associated riparian ecosystems (Johnson and McCormick, 1978). Even though riparian zones are not easily delineated, they are composed of mosaics of landforms, communities, and environments within the larger landscape (Gregory *et al.*, 1991).

Riparian zones range in width from a few to hundreds of meters. They can be found along ephemeral stream channels, such as southwestern arroyos that carry water only during rain or snowmelt wet periods, to perennial streams and floodplains, such as the densely wooded banks of rivers in the Pacific Northwest (Obedzinski *et al.*, 2001). Their vegetation varies from aquatic graminiod-sedge wet meadows to extensive forests. The health of a western riparian ecosystem is usually measured in terms of watershed level function, because of the ability to filter out large quantities of sediments, nutrients, pesticides, animal wastes, and other nonpoint source pollution (Obedzinski *et al.*, 2001). Riparian vegetation influences light penetration, air and water temperatures, and trophic interactions as the transition between aquatic and terrestrial zones. Large woody debris and litter associated with riparian vegetation are often necessary for productive fish habitats, and influence the physical, chemical, and biotic characteristic of riparian and instream ecosystems (Naiman *et al.*, 1992). However, in some riparian ecosystems, herbaceous plants provide the functions supplied by woody plants in other locations (Baker *et al.*, 2004).

In this article, we provide a description of the major threats addressed in the literature, discuss the type of literature we reviewed, quantify the threats addressed therein, and look at the spatial and temporal distribution of these threats. Analysis will show how some traditionally viewed threats, such as grazing, which according to the reviewed literature was considered a dominant threat in the 1980s and 1990s, have been diminishing in their extent, while other threats, such as invasive aquatic and terrestrial species, dams and, in recent years, climate change are increasingly more pervasive in the scientific literature.

In evaluating the impact of riparian threats, it is important to comprehend the nature, dynamics, and trends of past disturbances. Understanding and managing riparian systems requires recognition of the role of disturbance and the evolutionary experience of riparian organism within the context of regional ecosystems. If and when causes are understood, management changes that have real positive impacts can be designed and implemented. Hence, the objective of this paper is to aid managers and decision makers responsible for these systems by providing a temporal and spatial assessment of the types of threats which scientists and policy makers have publicly discussed over the course of two-thirds of a century.

DESCRIPTION OF THE MAJOR THREATS ADDRESSED IN THE LITERATURE

Grazing

There are more publications in the literature that discuss grazing as a threat to western riparian ecosystems than any other single threat. However, as livestock decreased across the West, expanding populations of native ungulates, particularly elk (*Cervus elaphus*), have raised the potential to cause significant riparian impacts (Clary and Kruse, 2004). Ecological impact concerns have been identified in four areas (Kauffman, 1988): (1) soil compaction, (2) herbage removal, (3) physical damage to plants, and (4) changes in fluvial processes that may eliminate germination sites for woody vegetation.

Herbage utilization by domestic or wild grazers can influence the ecological character of vegetation by altering structure and species composition (Kauffman and Krueger, 1984). Generally, this change occurs through the selective grazing habits, distribution, and intensity of different types of herbivores, and the sensitivity of individual plant species to animal traffic and feeding. Kauffman and Krueger (1984) noted that riparian overgrazing and site degradation favored the replacement of native bunch grasses with Kentucky bluegrass (*Poa pratensis*) in northeastern Oregon. In many locations, the most important cause for unsuccessful riparian plant reproduction was grazing and trampling by domestic livestock (Ehrhart and Hansen, 1997). Grazing of cottonwood seedlings was reported to be a major factor limiting regeneration along a southern Arizona creek (Glinski, 1977). In Yellowstone National Park, a 95% decline of tall willows (*Salix bebbiana*, *Salix boothii*, *Salix lutea*, and *Salix geyeriana*), and a virtual elimination of willow seed production was due to repeated elk browsing (Kay and Chadde, 1991).

Cattle, sheep, and elk all have contributed substantially to geomorphic alterations of riparian ecosystems (Medina, 1996). Grazing disrupts aggradation processes in riparian ecosystems through the cumulative effect of herbivory and alteration of the vegetation and soil matrix by hoof action (Neary and Medina, 1996). The loss of riparian vegetation leads to a weakening of streambanks and disruption of substrates that armor channel bottoms and precipitates channel incisions.

Eventually, channels lose their riffle areas, streams migrate laterally, pools shallow out, water tables lower, and riparian vegetation composition shifts from hydric to more mesic species.

Dams

One of the consequences of dam construction that provides both a threat and a benefit to riparian ecosystems is flow regulation. Dams have the effect of reducing peakflows for increased water storage, and increasing or decreasing low base flows. These changes in flow regime can have a substantial affect on both riparian plants and aquatic biota. Crawford *et al.* (1996) and Groeneveld and Griepentrog (1985) reported declines in riparian vegetation in flow regulated rivers. Beauchamp and Stromberg (2007) measured no significant changes in *Populus* spp. and *Salix* spp. stands on the Verde River of Arizona due to flow regulation, but *Tamarix* establishment increased. Beauchamp *et al.* (2006) noted marked declines in herbaceous species richness and abundance due to flow regulation. Fluctuating flows produced by flow regulation for electricity generation and irrigation have been known to reduce periphyton density in rivers (Benenati *et al.*, 1998).

Construction of a dam in Montana reduced the magnitude and intensity of floods to the point that cottonwood density decreased significantly over a 45-year period (Bradley and Smith, 1986). In this case, even though recruitment of cottonwood seedlings continues to occur, survival is low. The problem is that not enough seedlings are growing in the critical zone. This zone needs to be sufficiently above water level to ensure rooting before high water disturbs seedling establishment. It must also be near enough to the surface water table to draw sufficient moisture to survive dry periods. Rood *et al.* (1995) found similar results with dam construction on rivers in southern Alberta.

Hadley and Emmett (1998) found the opposite to be true with dam construction on a tributary of the South Platte River. A dramatic shift in the riparian plants from sparse grasses to dense woody vegetation occurred after dam construction. This rapid change was linked to channel scour, sediment deposition declines, fewer scouring peakflows that damaged woody plants, and an increase in dry season low flows. In some parts of the West, riparian woody vegetation is more abundant now due to human-induced disturbances than in pre-European times. Thus, some declines in woody riparian plants currently observed in the western United States (U.S.) may actually be resilience in the riparian ecosystem exhibiting slow recovery to a natural dynamic state.

Land Use Change

Riparian ecosystems provided areas for agriculture for Native Americans before the arrival of European settlers (National Academy of Science, 2002). With the settlement of the West in the latter half of the 19th Century, riparian areas were extensively developed and altered. This continues today in smaller rivers like the Verde in Arizona (Tellman *et al.*, 1997), but also along larger rivers with broad alluvial plains like the lower Colorado River in Arizona and California (Johnson, 1978), the Sacramento River in California (Spotts, 1988), and the Columbia River in Oregon and Washington.

Urbanization, specifically, is a rather localized threat to riparian ecosystems of major streams like the Colorado, Rio Grande, Columbia, Snake, Missouri, and Sacramento rivers (Brinson *et al.*, 1981; Roelle and Hagenbuck, 1995; Braatne *et al.*, 2008). However, the associated threats produced by increased human presence in the West produce extensive and intensive impacts across the region (Stromberg *et al.*, 2004).

Invasive Species

The two major invasive plants, which according to the literature pose a threat to western riparian ecosystems are Russian-olive (*Elaeagnus angustifolia*), a native of Europe and western Asia, and tamarisk (*Tamarix chinensis*). Both were introduced into the U.S. in the early 1800s from Europe, and are of concern because of their ability to colonize riparian sites and exclude native species (Howe and Knopf, 1991). However, in parts of the West, invasive fish, crustaceans, and mollusks are creating major threats to native fisheries and the aquatic parts of the riparian ecosystem (Rinne, 1993).

The life history of the invading species has contributed to their success (Horton, 1977). Tamarisk and Russian-olive negatively affect native riparian species germination and establishment in three ways: (1) the exotic species have a longer period to exploit suitable germinating conditions, (2) shading by exotics minimizes the potential for successful cottonwood regeneration, and (3) the exotics are better able to compete for shade and limited moisture (Howe and Knopf, 1991) and to tolerate drought (Cleverly *et al.*, 1997).

Coupled with its ability to increase soil salt concentrations through autogenic processes, tamarisk has a high salt tolerance that gives it a competitive advantage over many native species (Stromberg *et al.*, 2004, 2007). Tamarisk combines fast growth in wet years with extreme tolerance of water and heat stress

(Cleverly *et al.*, 1997). Reduction in streamflow by climate change, flow regulation, water diversion, or dam construction further aggravates the tamarisk threat. In the Southwest, tamarisk has invaded many mesquite bosques and cottonwood/willow forests along the Rio Grande, the San Pedro, and the lower Colorado River (Stromberg *et al.*, 2007). In Colorado, deteriorating riparian cottonwood stands are being replaced by Russian-olive, raising concerns about the future ecological status of these important riparian ecosystems. In New Mexico, the Rio Grande riparian system will likely be dominated by exotic species within the next century (Howe and Knopf, 1991).

Reductions in riparian plant diversity, faunal-plant assemblages, uniqueness, and critical habitat not only influence terrestrial wildlife and vegetation, but also affect macroinvertebrates within the stream. Changes in the quality of stream organic material inputs together with alterations of the duration, intensity, and quality of light transmitted to the aquatic environment, affect the quality, types, and abundances of substrates for many micro and macroinvertebrates (Obedzinski *et al.*, 2001).

Timber Harvesting

Settlement of the West in the 19th Century resulted in removal of woody riparian vegetation and the decline of some of these ecosystems. Sands and Howe (1977) indicated that there were about 300,000 ha of riparian woodlands in California in the first half of the 19th Century. By the end of that century, these woodlands had been reduced significantly for fuel wood, fence posts, and building materials, and converting land to agriculture. By 1977, only 4,725 ha of the 19th Century riparian woodlands remained intact.

A similar reduction in riparian forests also occurred in the Southwest. Forest harvesting combined with grazing, conversions to agriculture, and water regulation reduced riparian woody vegetation to only 5% of what was originally found at the beginning of the western settlement (Johnson and Haight, 1984).

Logging affects western riparian ecosystems through tree falling, log skidding, road construction, and direct removal of vegetation (DeBano and Schmidt, 1989a,b). The first three factors compact and disturb soil, which increases erosion, depresses growth, and further stresses residual vegetation. Removal of vegetation can alter thermal regimes, increase soil loss, diminish ecological characteristics such as structural diversity, alter species composition, and improve site conditions for invasions by nonnative plants and other biota.

Climate Change

Climate change can influence riparian ecosystems due to the reliance of these systems on the presence of water (Naiman *et al.*, 2002). Excessive water (floods) or insufficient flows (drought) due to climate change can affect both the biological and physical compositions of riparian areas (Abrahams *et al.*, 1995; Dixon *et al.*, 2009). Barnett *et al.* (2008) attributed many of the observed changes affecting riparian ecosystems such as river flow, snow packs, temperature, etc. to human activities. Future climate changes will certainly produce vegetation shifts (Huxman and Scott, 2007; Chambers and Pellant, 2008) that may or may not be mitigated with restoration techniques (Seavy *et al.*, 2009).

As a major feature of climate change, drought creates stress by reducing the ability of plants to photosynthesize, and by limiting the moisture necessary for germination or the seasonal flooding required by flood-adapted species such as cottonwood (Obedzinski *et al.*, 2001). Kranjcec *et al.* (1998) found that groundwater level declines and the lack of seasonal flooding had serious effects on cottonwood reproduction and establishment. Drought also can influence native riparian species because they cannot compete with exotic species better adapted to drier conditions and minimal flooding. Cleverly *et al.* (1997) and Stromberg *et al.* (2007) noted that summer flooding, no flooding, or reduced or altered water tables enabled tamarisk invasion of cottonwood-willow systems in Arizona. Johnson *et al.* (1976) identified the importance of fresh alluvium for the establishment of pioneer species such as cottonwood (*Populus* spp.) and willow (*Salix* spp.). If this alluvial development is prevented by drier weather patterns, then species better adapted to nondisturbance, such as oak (*Quercus* spp.), might begin to dominate.

Recreation

Recreationists are frequently drawn to riparian areas in the West because of the water resources and lush vegetation (Winter, 1993). Despite their value to land managers, recreation activities such as camping, hiking, and off-road vehicles use are posing threats to western riparian systems (Aitchison *et al.*, 1977; Johnson and Carothers, 1982). Heavy recreational use can result in damage such as (1) reducing density and diversity of herbaceous plants, (2) lowering tree and shrub vigor, (3) eliminating seedlings and younger trees, (4) increasing tree diseases, (5) shifting plant species diversity in favor of disturbance-adapted species, and (6) increasing the potential for exotic species spread.

Recreation threats are often linked to other threats. Manning (1979) found that younger trees were reduced or eliminated on moderately or heavily used recreational sites. In areas of concentrated use, aspen stands have shown damage from a variety of recreation-related impacts including bark carving, soil trampling, firewood cutting, and removal of young suckers. The results of this damage are: (1) reduced or no advanced regeneration, (2) tree vigor reduction in all size classes, and (3) increased susceptibility to insect attack and disease spread. Changes in flow, climate change, and insect and disease stresses are commonly entwined with recreation impacts.

Water Quality – Salinity

Water quality changes in streams, lakes, and ponds associated with riparian ecosystems are associated with other threats, chiefly agriculture, grazing, mining, fire, forest harvesting, urbanization, and recreation. While mining, recreation, and urbanization produce numerous, but localized nonpoint source pollution problems, agriculture, including livestock grazing, probably is the largest threat to riparian ecosystems due to nutrient release from fertilizers, bacteria associated with animal fecal material, and salinization of irrigation return waters (Brown, 1984; Mueller and Moody, 1984). In the Southwest, salinization of tributaries and the main stem reaches of the Colorado River has been a major water quality problem (Johnson and Riley, 1984; Jonez, 1984).

Water Diversion

Dams and the irrigation diversion canals often associated with dams have significantly altered habitat for woody riparian vegetation in many parts of the West. Stromberg *et al.* (2004, 2007) surmised that the altering of water flows, especially by diversions, is among the greatest threats to Sonoran cottonwood-willow ecosystems. Rood *et al.* (2005, 2007) rated river damming and associated water diversion right after livestock grazing and agriculture as primary causes of decline in cottonwood riparian ecosystems.

Many riparian species are sensitive to changes in the hydrologic regime that affect flooding periodicities and water table depth. Cottonwood in particular has been significantly affected by water diversion. Like many western riparian species, cottonwoods are adapted to spring flooding and high water tables. Water diversion has not only significantly reduced flooding events, but also has resulted in substantial lowering of riparian water tables to depths that prevent newly established woody plants like cottonwoods from obtaining moisture. In some cases, root systems of riparian tree species are not able to grow fast enough to keep up with dropping water table levels (Groeneveld and Griepentrog, 1985).

In the Southwest, primary, secondary, and tertiary tributaries of all major rivers have been affected by water diversions of some type. By the middle of the 20th Century, the effects of water diversion on the Gila-Salt-Verde River system were so great that $<50\%$ of their original length remained free flowing (Johnson and Haight, 1984).

Groundwater Depletion

Groundwater depletion is a function of consumptive use by urban and agricultural users, flow regulation, and dam construction. These alterations of flow regimes have markedly lowered groundwater levels in some areas. Groundwater is important to riparian vegetation during periods of drought or in areas of low seasonal precipitation (Groeneveld and Griepentrog, 1985; Stromberg *et al.*, 1992). Stress on mesquite woodlands increased with increasing groundwater withdrawal from an ephemeral creek in Arizona (Stromberg *et al.*, 1992), and elsewhere in the Southwest (Stromberg *et al.*, 2004). Although summer rains and seasonal high flows temporarily reduced water stress, the effects of a declining water table usually are not mitigated and ultimately lead to continued stress and riparian ecosystem declines.

Diversions of rivers and groundwater pumping in alluvial riparian plains for agriculture irrigation have contributed to water quality problems and groundwater depletion (Johnson and Haight, 1984; Johnson and Riley, 1984; National Academy of Science, 2002).

Fire

The role of fire in the dynamics of riparian zones is poorly understood (Dwire and Kauffman, 2003). Riparian areas along the Gila River in the Southwest periodically burned during dry periods (Baker *et al.*, 2004). In the Great Plains, tree-dominated riparian woodlands are somewhat limited by fire (Boldt *et al.*, 1978). Fire also affects germination and establishment of many obligate riparian tree species. Aspen seedling establishment has been observed to be greatest in riparian zones that had burned to mineral soil. Fires have a larger effect on shaping the ecological characteristics of riparian zones than was believed in the past (Pettit and Naiman, 2007).

Past and current research is exploring relationships among native and exotic plants and fire. For example, Busch and Smith (1995) found that tamarisk had a competitive advantage in water uptake over willow coppice sprouts on burned sites in the Southwest. Accumulation of flammable tamarisk leaf litter also may contribute to the occurrence of episodic fires that destroy native tree species such as willow (Smith *et al.*, 2009).

Wildland fires have natural sources of ignition but they are more closely a result of human activities (Stromberg *et al.*, 2004). Fires can affect the amount of sediment that reaches streams, alter the loadings of coarse woody debris into riparian areas, and can significantly affect the vigor and type of riparian vegetation (Baker *et al.*, 2004). Prescribed fires and wildfires of low-to-moderate severity usually do not cause much postfire sedimentation. By contrast, severe fires often produce enough sediment to overload the transport capacity of a stream. While this can provide ecological benefits for aquatic habitats in the short term, that same debris can cause long-term disruptions of fluvial, sediment, and biological processes (Davis *et al.*, 1988; DeBano *et al.*, 1996).

Mining

Mining has had impacts on riparian ecosystems throughout the western U.S. The major threats to riparian ecosystems have come from forest harvesting to provide mine timbers and fuelwood for underground mines. Placer mining as well as sand and gravel operations have altered flow and sediment regimes (Heifner, 1978; Andrews *et al.*, 1985). Mines have also had drastic impacts on water quality and altered fish habitats (Martin and Platts, 1981).

Multiple Threats

Riparian ecosystems in the West are being influenced by a variety of stressors. In most cases it is difficult to clearly distinguish the individual impact of each threat. The effects of an obvious threat might mask those of a more insidious one. For instance, Medina (1996) and Neary and Medina (1996) found that threats to riparian meadows in the White Mountains of Arizona caused by obvious cattle grazing were masking those already imposed by elk grazing and climate change. Thus, riparian ecosystem threats need to be examined carefully to determine causes and effect. In some instances this may not be possible. Furthermore, the presence of multiple threats to a riparian ecosystem can create a negative synergy, which can not be explained by any one individual threat.

ASSESSING THE LITERATURE

During our literature assessment, we looked at close to 1,000 articles, reports, books, and chapters, of which we used 453 for the analysis described here. Literature was obtained through searches at university libraries, online search engines such as the U.S. Forest Service “TreeSearch” and Google, as well as by looking at the reference sections of previously selected papers. Once we had chosen about 500 publications based on the criteria listed below, we started our assessment. During our evaluation a number of papers were eliminated from our consideration for various reasons leaving 453 papers. While this method did not guarantee that all “important” riparian papers were included, we believe that the sheer volume of publications provides a good representation of threats to riparian ecosystems in western North America in the scientific literature. To include a paper in our study, it needed to describe at least one threat to a riparian ecosystem in western North America (U.S., Canada, and Mexico). During our review we divided publications into five different categories. We considered a publication a *research paper*, which was our main focus, if the author(s) asked a research question and conducted an experiment, such as using a cattle exclosure to determine the impacts of cattle grazing (Bryant, 1982; Roath and Krueger, 1982; Bohn and Buckhouse, 1985; Schulz and Leininger, 1990; Allen and Marlow, 1991) or running numerous simulations to determine the effects of climate change on riparian ecosystems (Barnett *et al.*, 2008; Dixon *et al.*, 2009). These papers usually only address one threat at a time. We regarded a publication as a *management paper* if it described management action, application or implementation without experimental design. An example would be a description of stream modification to benefit a specific fish population and the following results (Andrews *et al.*, 1985; Wesche, 1985; Konopacky *et al.*, 1986). (This is how we did it and this is what happened.) A publication illustrating one or more threats to riparian ecosystems summarizing the work of others was labeled a *literature review* (Belsky *et al.*, 1999; Malmqvist and Rundle, 2002; Poff and Zimmerman, 2010). *Historical comparison papers* compare a specific riparian site of at least two points in time usually more than 50 years apart (i.e., 1880 *vs.* 1980) and illustrated the differences at each point in time, usually using photographic comparisons (Betancourt, 1990; Starnes, 1995). The documented change was then associated with a specific cause, which is considered a threat to riparian ecosystems as described below. If a publication gave an overview of threats to riparian ecosystems in a broad discussion or suggested a general direction in which riparian management should be headed (Chambers, 2008; Sada, 2008) or what wide-ranging protocols and policies should be followed (McCormick *et al.*, 2009; Seavy *et al.*, 2009), it was categorized as a *policy paper*.

Of the 453 publications included in our evaluation we assessed 171 *research papers* (38%), 98 *policy papers* (22%), 86 *literature reviews* (19%), 71 *management papers* (16%), and 27 *historical comparisons* (6%). The majority of all publications types addressed only one threat at a time (see Figure 1). With the exception of the *policy paper* category a single threat was addressed about half of the time or more in all publication types. About three quarters of the *research papers* dealt with a single threat. The most diversity in the number of threats addressed was found in the *policy paper* and *literature review* categories. The maximum number of threats addressed by any one publication was 12 by one *literature review* (to be expected) and one *research paper* (not expected – perhaps misclassified).

For our analysis we selected one primary threat for each paper. This task was simplified since more than half of the publications assessed herein only addressed a single threat. Furthermore, the majority of the papers describing multiple threats tended to focus on a primary threat and mentioned other threats in their literature review or discussion. There were only a handful of publications where a primary threat was not obvious. Here, we chose the first threat that was described in detail as the primary threat.

RESULTS

The top four of the 22 threats to riparian ecosystems, are considered the primary threat in about two-thirds of the publications we assessed (see Table 1). Grazing (or the improper management of livestock in riparian zones) alone accounted for almost one-third (31%), dams were a distant second (14%), followed closely by land use change (12%). Invasive species [mostly salt cedar (*Tamarisk* spp.) and Russian-olive (*E. angustifolia*)] ranked fourth (9.9%), while timber harvest rounded out the top five with a mere 5.3%. The remaining 17 primary threats, their total number of occurrences as such in the literature and the corresponding percentages are listed in Table 1.

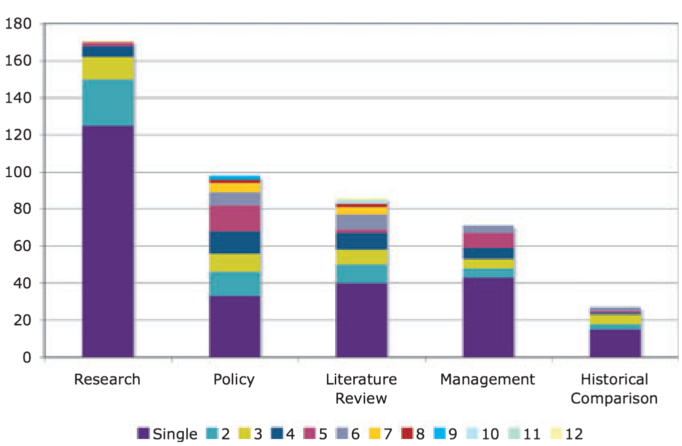

FIGURE 1. Relative Frequency Distribution of the Number of Threats Addressed by Each Type of Paper.

Spatial Distribution of Threats

Next, we looked at where threats to western riparian ecosystems are reported in the existing literature. The top three states, namely Arizona (22.5%), California (17.4%), and New Mexico (11%), are mentioned in half of the literature where states or sites within these states (such as the Grand Canyon National Park in Arizona) are mentioned (see Table 2). Colorado is a close fourth (10.7%) and together with the top three most mentioned states is located in the southwestern part of the country, which as a general

TABLE 1. Threats to Riparian Ecosystems Addressed in the Literature Are Ranked Here by the Number of Appearances as Primary Threat and Percentage Thereof in This Assessment of 453 Publications.

Rank	Primary Threat Addressed	Number of (research) Publications	Percentage of (research) Publications
1 (1)	Grazing	140 (59)	30.9 (34.5)
2 (2)	Dams	62 (27)	13.7 (15.8)
3 (3)	Land use change	54 (11)	11.9 (6.4)
4 (2)	Invasive species	45 (27)	9.9 (15.8)
5 (7)	Timber harvest	24 (3)	5.3 (1.8)
6 (5)	Climate change	20 (7)	4.4 (4.1)
7 (4)	Recreation	18 (8)	4.0 (4.7)
8 (7)	Salinity	17 (3)	3.8 (1.8)
9 (6)	Water diversion	14 (6)	3.1 (3.5)
10 (6)	Groundwater pumping	13 (6)	2.9 (3.5)
11 (6)	Fire	12 (6)	2.6 (3.5)
12 (8)	Mining	11 (2)	2.4 (1.2)
13 (9)	Nonpoint source pollution	6 (1)	1.3 (0.6)
14 (13)	Fuel management	4 (1)	0.9 (0.6)
15	Road construction	3 (0)	0.7
16	Fire suppression	2 (0)	0.4
16	Insect and diseases	2 (0)	0.4
16 (8)	Woody encroachment	2 (2)	0.4 (1.2)
17 (13)	Beavers	1 (1)	0.2 (0.6)
17	Beaver trapping	1 (0)	0.2
17 (9)	Parasitism (cowbirds)	1 (1)	0.2
17	Pollution	1 (0)	0.2

Note: The numbers in parentheses refer to the ranking of threats in research papers and the total number of research papers addressing these threats.

TABLE 2. The Location of Study Sites in Western States Represented Throughout the Literature Are Ranked Here by the Number of Appearances and Percentage Thereof in This Assessment of 453 Publications.

Rank	State	Number of Publications	%
1	Arizona	102	22.5
2	California	79	17.4
3	New Mexico	50	11.0
4	Colorado	48	10.6
5	Oregon	44	9.7
6	Nevada	31	6.8
7	Utah	24	5.3
8	Idaho	22	4.9
9	Wyoming	20	4.4
10	Montana	16	3.5
11	Washington	14	3.1
12	Texas	13	2.9
13	South Dakota	3	<1
14	Alaska, North Dakota, Oklahoma	2	<1
15	Kansas, Missouri, Nebraska	1	<1

TABLE 3. Publications That Did Not Specify a State but Rather a Region or General Area, Are Ranked Here by the Number of Appearances in This Threats Assessment.

Rank	General Region	Number of Publications
1	Western U.S.	53
2	Southwest	18
3	Western Canada	11
3	Western North America	11
4	Pacific Northwest	8
5	Colorado River Basin	7
6	Intermountain West	6
6	Mexico	6
7	Great Basin	5

region, is referred to by an additional 4% of papers, when no specific states are given (see Table 3). Arizona, California, New Mexico, and Colorado are also part of the Colorado River Basin, which is a separate region in a number of publications.

Research Papers

For further analysis of the existing literature we focused on publications describing research. The other categories of papers typically had a tendency to describe the symptom of degrading riparian ecosystems rather than the causes. *Research papers* often focus on the underlying causes of the degradation and attempt to determine the actual threats to riparian areas. When comparing the primary threats in the entire body of literature, we also assessed the main threats in *research papers* separately (see Table 1). It is noticeable that grazing and dams top both lists, and land use change places third, even though it makes up twice the percentage of research publications than in the general literature (12 *vs.* 6%). Invasive species are also the second highest ranked threat in the research literature but only the fourth highest in the general literature with 16 *vs.* 10%. Timber harvest is considered a threat in over 5% of the general literature, but <2% in the research literature. Additionally notable is that salinity and mining received twice the attention in the general literature they received in the research literature – percentagewise.

In this assessment, we also looked at the *spatial* (Figure 2) and *temporal* (Figure 3) distribution of the research literature. When examining the spatial distribution of riparian threats research, several trends become obvious. For one, the majority of the research appears to have been conducted in Arizona, the only state in the nation with a negative water balance (Fierro and Nyer, 2007). Similar to the distribution of all publications assessed within this paper, California, New Mexico, Colorado, Oregon, and Nevada, respectively, make up the top six western states, where research on riparian threats was conducted. With the exception of coastal areas of California and Oregon, these states are located in the arid and semiarid region of the western U.S., where water resources are scarce. It is also noteworthy that grazing in these states is just one of many threats, unlike Oregon where it is considered – according to the research – to be the major threat to riparian areas. In Colorado and Nevada grazing is the most researched threat among many threats, but it is far from dominating the research as is the case in Oregon. In Arizona invasive species and dams and in California land use change are threats prompting the most research, while in New Mexico grazing, invasive species and dams equally share rank number one in the research literature.

In the temporal analysis there are also several noteworthy observations. For example, the first research publication identifying a threat to a riparian area dates back to the 1930s and addresses invasive species. This threat has remained in the research literature throughout the decades, but so far has not reached the threat "super-status" that grazing reached in the 1980s, when it dominated almost half of all the research conducted on riparian threats. Since then conducting research on grazing as a threat in riparian zones has become less prevalent, but it still remains a major concern. Timber harvest, which was considered a threat in some states in the 1970s and 1980s, disappeared in the research literature in the 1990s due to declines in harvesting on Federal lands, but reappeared this century. Climate change

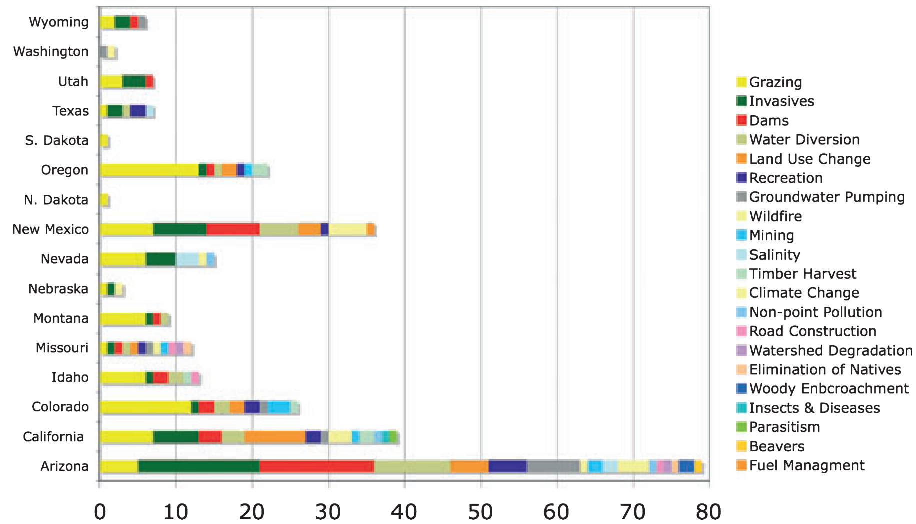

FIGURE 2. This Bar Graph Shows Which Threats Research Addressed in What State and How Many Times.

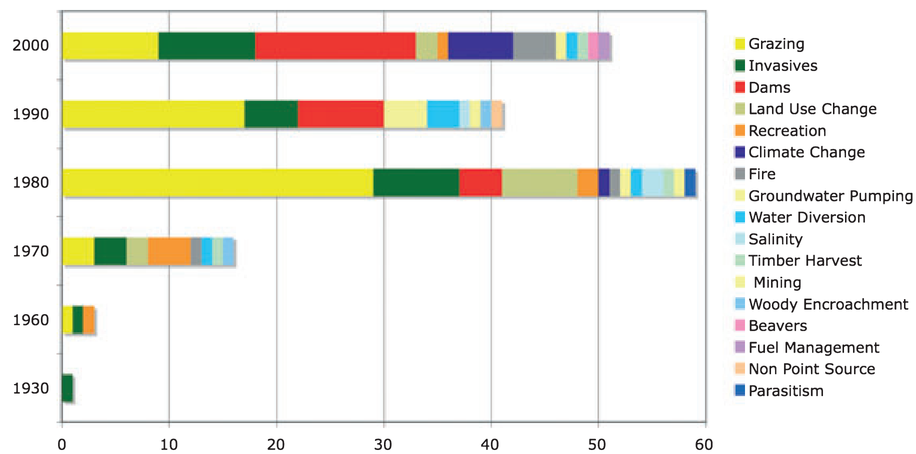

FIGURE 3. This Bar Graph Shows Temporal Distribution of Research Papers Addressing the Primary Threats to Riparian Ecosystems.

as a threat to riparian ecosystems is a newcomer to the scene this century. And so far (2010 was the latest publication included in this assessment) climate change already ranks as the fifth largest threat being researched. It is also interesting to note that the 1980s saw a peak of doing research on riparian threats.

DISCUSSION

So what does it all mean? Assessing the existing literature for threats to riparian ecosystems revealed trends, which may not have been so obvious to the casual observer, but also confirmed some likely assumptions. It should not be surprising, for example, that the only state in the nation that has a negative water budget, namely Arizona, has the most publications, research and otherwise, addressing the threats to its riparian zones. In fact, Arizona has lost 95% of its riparian habitat in the past 150 years. Other western states, California, Colorado, New Mexico, and Nevada, where water is scarce and ecosystems compete with humans for the precious source of life, publications address the threats to the dwindling riparian zones. In states with more mesic environments (western Oregon, Washington, Idaho, and Wyoming), the focus of riparian threat analyses is geared toward fisheries and aquatic environments. Other trends being revealed by the spatial analysis show that where water is scarce the sheer number of threats is higher than in areas where water is abundant. For example, Arizona has 17 different threats addressed by research and California has 13, *vs.*

Idaho with 6 and Washington with a mere 2. It is also noticeable that the research in the wetter states focuses more on the threat that grazing poses, whereas in the dry states improper bovine management is just one of many issues faced by managers of riparian zones.

The temporal analysis indicates that grazing, as a threat to riparian ecosystem, has been the premier threat discussed in the literature for close to five decades. While it dominated the research conducted in the 1980s, its popularity as a research topic has been slowly and steadily declining since. However, it is still the major threat being assessed in the scientific literature, as different approaches to livestock management in riparian zones are explored. Invasive species and the management thereof in riparian zones has been a steady staple of research throughout the existence of research on threats to riparian ecosystems. While it never dominated the research – with exception of the 1930s, when it was the only research conducted on riparian threats (and the only paper from the 1930s) – invasive species have been a consistent and persistent threat throughout. It is also interesting to tease out that dams were not investigated as a threat to riparian areas until the 1980s but have been prevalent ever since. The most interesting threat may be climate change, which is the latest, in terms of recognized threats to riparian systems in the research literature. It may have appeared late, but it climbed the list quickly and is the fourth most researched threat this century and sixth biggest threat overall, within less than a decade. Comparing research-based literature to the other categories of publication assessed in this paper also provides some insights. Research tends to focus more on the causes of the threats to riparian ecosystems, some of which, that is, groundwater pumping and water diversion, are not as spectacular as let's say timber harvesting, which is a popular threat only in the non-research based literature, while the other two are not. Also, the scope or number of threats to riparian systems addressed in a particular paper is typically fewer in the research category due to the constraints of designing experiments. It should also be noted that often threats to riparian zones are related or overlapping as far as the type and magnitude of degradation they cause. For example, the most successful invasive species infestations are typically in riparian areas where the hydrologic regime has been significantly altered. Three of the individual threats covered in the literature pertain directly to hydrologic alteration namely dams, groundwater pumping, and water diversion, which combined make up more than one-fifth of all the threats addressed. Furthermore, all of the threats due to biotic or abiotic changes in site characteristics (e.g., plant cover loss, ecotype change, sedimentation, soil loss, etc.) are indirectly impacting hydrologic regimes of western riparian ecosystems. This group includes: grazing, timber harvesting, mining, land use change, woody encroachment, invasive species, fire, and watershed degradation. There are also threats, such as salinity, nonpoint source pollution, and elimination of native species that are the by-product of other threats. The reality of the overwhelming complexity of riparian systems and their role in the landscape requires an examination of threats individually for quantitative purposes, but also collectively and qualitatively to expand our understanding of riparian systems and the sources of their degradation.

SUMMARY AND RECOMMENDATIONS

We assessed and analyzed 453 publications, dominated by research papers, on their content about threats to riparian ecosystems. The authors believe to have covered a good representation of the existing literature from the 1930s to 2010. Most publications found on this topic, covered arid and semiarid regions (especially within the research paper category). Grazing has been declining in its representation in the literature on threats to riparian ecosystems; however, is still a concern in most western states. Research papers that examine the causes of riparian degradation, not only its symptoms, are the most informative publications as they typically examine a single threat quantitatively. We recommend that future research focus on the causes of degradation rather than the symptoms. If and when causes are understood, management changes that have real positive impacts can be designed and implemented. The literature covering threats to riparian ecosystems is vast, providing a plethora of information for managers, decision makers, and other interested parties. The authors hope that the assessment provided here will help those interested in the threats to riparian ecosystems in western North America to gain a better perspective in terms of what has been written in the literature.

A complete annotated bibliography of the literature reviewed, can be found at: http://www.rmrs.nau.edu/awa/ripthreatbib.

A USDA Forest Service General-Technical Report is also forthcoming.

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