Large Woody Debris in Hot-Desert Streams: An Historical Review

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Abstract

Large-particulate organic debris is denied to present-day desert streams because of interception by impoundments and as a result of decimation of formerly extensive riparian vegetation. Historical records indicate a substantial, but sporadic, input of coarse debris, which was reduced to finer particles through molar action in canyon-bound reaches of desert rivers. Historical changes, functions of large debris in the systems, and probable future conditions are reviewed.

Introduction

The Colorado River system of the American Southwest originates high, forested mountains, then traverses lowlands of the sub-tropical Sonoran Desert on its way to the Pacific Ocean. Conifers and mixed hardwoods surround higher elevation tributaries, with little specialization to mark riparian zones. At intermediate elevations, precipitous terrain surrounds the river and its tributaries, and the watercourses are often canyon bound. Riparian vegetation is poorly developed in erosive canyons, restricted to protected places or to marginal habitats above levels of major floods. In their lower course desert rivers pass through alternating canyons and broad alluvial valleys. Riparian vegetation at low elevation is densely developed in a band along the immediate banks, and is markedly different from that of adjoining landscapes (Minckley and Brown, 1982; Ohmart and Anderson, 1982).

Naiman (1981) included the general absence of large-particle organic debris as a basic characteristic of desert streams. We concur that large wood rarely contributes to heterogeneity in today's desert stream ecosystems; however, we document that historically this was not the case. Absence of coarse debris in present systems is largely an artifact resulting from interception of drifted debris by dams and other obstructions (Webster et al., 1979), and from destruction of riparian communities. Presence of large wood in these systems in times past may have been sporadic, but nevertheless must have been a significant factor in the ecosystems.

Descriptions of the Systems

Vast elevational relief and coincident climatic variation in the American Southwest results in marked altitudinal zonation of vegetation (Brown, 1982). This phenomenon has stimulated a number of classifications of biotic communities, of which the Life-zone Concept of C. Hart Merriam (1890, 1898) is most familiar to ecologists. Riparian vegetation also responds to altitudinal constraints, and thus occupies longitudinal zones along streams (Fig. 1). Species extend further downstream than is typical of their altitudinal distributions as a result of downstream transport of propagules, mesic streamside conditions that result in climatic features in common with higher-altitude habitats, weather amelioration at lower elevation through down-canyon drain of cold air from adjacent mountains, and other factors (Lowe, 1964; Campbell and Green, 1968; Minckley and Brown, 1982).

Natural low-desert riparian communities consist of spectacular gallery forests of tall trees dominated by Fremont Cottonwood *(Populus fremontii)* and Goodding Willow *(Salix gooddingii)* (Fig. 2). Understory communities include bosque-forming Mesquite *(Prosopis velutina, P. pubescens)* on terraces, shrubs such as Seepwillow *(Baccharis salicifolia)* and Coyote Willow *(Salix exigua)* in wetter places, and Arrowweeds *(Tessaria sericea, Pluchea camphorata, P. purpurascens),* Quailbush *(Atriplex lentiformis),* Desert Broom *(Baccharis sarothroides),* and salt-tolerant chenopods *(Atriplex polycarpa, Suaeda torreyana, Allenrolfia occidentalis)* in drier zones. At intermediate elevations other large tree species including Arizona Sycamore *(Platanus wrightii),* Velvet Ash *(Fraxinus pennsylvanica* var. *velutina),* and Arizona Walnut *(Juglans major)* may occur along with Mesquite, Hackberry *(Celtis pallida,* C. *reticulata),* and shrubs such as Burrobush *(Hymenoclea* spp.), Wolfberry *(Lycium* spp.), and others. These dense and diversified riparian communities are important components of hot-desert ecosystems. They provide an essentially tropical habitat, forming mesic corridors through arid zones, and support remarkable densities of seasonal, transient, and perennial animals (Minckley and Brown, 1982; Ohmart and Anderson, 1982).

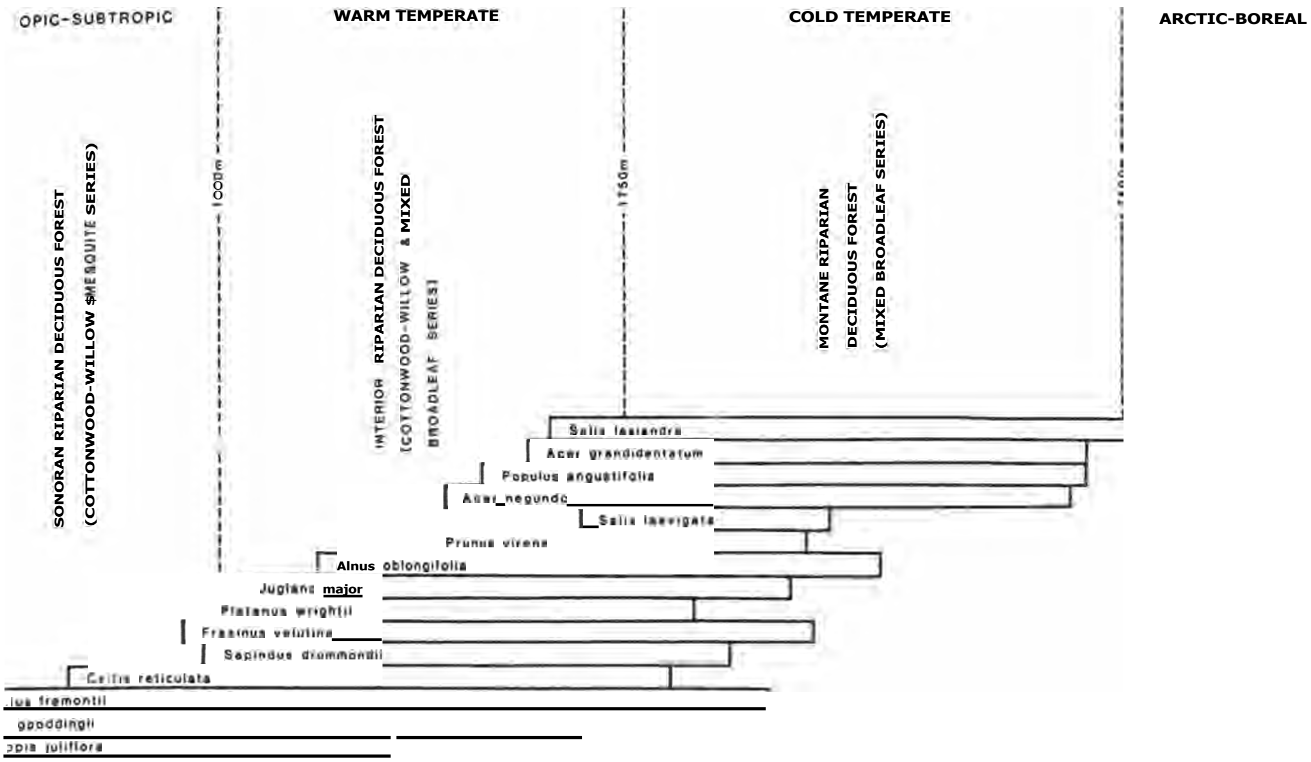

Figure 1. *Semi-diagrammatic representation of altitudinal zonation of woody riparian plant communities in the American Southwest; from Minckley and Brown (1982).*

orical Review

ie presence of riparian gallery forests, densely vege- 1 floodplains, and substantial marshlands along Sono- Desert watercourses has been reviewed and doc- nted by, am::ng others, Grinnell (1914), Sykes (1937), :ings (1959), Hastings and Turner (1965), Cooke and /es (1976), Ohmart and Anderson (1982), Minckley and vn (1982), Davis (1982), and Hendrickson and Minckley 4). Photographs of such habitats were provided by y of those authors. Further lithographic or photo- hic and narrative documentation for dense riparian sts and accumulations of large, woody debris in and g desert rivers may be found in works by Pattie (1833), ory (1848), Bell (1869), Olmstead (1919), Burkham (1970, 1976a-c) Turner (1974), and Kipple (1977) for the Gila River basin, Arizona-New Mexico, and Pattie Leopold (1949), and Sykes (1937) for the lowermost Drado River, Arizona-California, and Sonora, Mexico. :res 3 through 5 further illustrate these habitats, as do following selected quotations from early literature rces.

ne of the earliest accounts was that of Pattie (1833), a :er trapper who frequented Sonoran Desert streams n 1824 through 1828 (brackets [] ours):

> first day [in December, 1824 on the Gila River in what is now Mexico] we were fatigued by the difficulty of getting ugh the high grass, which covered the heavily timbered bot- [p. 53].

> river here was beautiful, running between banks covered tall cotton-woods and willows [December, 1824; p. 55].

> 'J ad pitched our camp near the bank of the [San Pedro] river [eastern Arizona] in a thick grove of timber, extending about a hundred yards in width [March, 1825; p. 64].

> . the Helay [Gila River], which is here [near the present site of Phoenix, Arizona] about 200 yards wide, with heavily timbered bottoms [February, 1826, p. 91].

Emory (1848) traveled essentially the same route as Pattie, and he and his men chronicled similar conditions in 1846:

> [In what is now New Mexico] The bottom of the [Gila] river is narrow, covered with large round pebbles. The growth of trees and weeds was very luxuriant; the trees chiefly cotton-wood, a few sycamore, mezquite, pala (the tallow tree of our hunters), a few cedars, and one or two Larch. There were some grape and hop vines [October, 1846, p. 621

> The valley of this [Gila] river is quite wide and is covered with a dense growth of mezquite (acacia prosopis) cotton wood, and willow, through which it is hard to move without being unhorsed [near the mouth of the San Pedro River, November, 1826; p. 75].

> [Approaching the mouth of the Gila River, November 1826] The bottoms of the river are wide, rich, and thickly overgrown with willow and a tall aromatic weed [p. 91] ... the bottom of the river constantly received deposits [of sand) from . . . [adjacent lands], which changed its bed frequently, as might be seen from the different growths of cotton wood marking the old land [p. 93].

Conditions along smaller tributaries also included large stands of riparian trees, and thus presumably substantial amounts of downed timber. Bell (1869) reported in detail on Aravaipa Creek and Canyon, south-central Arizona, based on a survey for potential wagon roads through the region in November 1867 (pp. 72-76, non-inclusive):

Figure 2. Gallery forest along uppermost Aravaipa Creek, south-central Arizona, 1976. Photograph by W. L. Minckley.

Figure 3. *Riparian forests on the Colorado River Delta, Sonora, Mexico, near the turn of the 20th Century. U.S. Bureau of Reclamation Photograph No. 115-VI-162.*

it vegetation fills up the space between the [Aravaipa] *walls; the undergrowth consists of willows, young trees, rass, reeds, &c., forming in many places an impenetrable and above them a succession of noble trees tower up the sky, as if striving to gain a glimpse of the upper world. grove of the loftiest cotton-woods and sycamores . . . we 'own our blankets for the first nights rest.*

tacles our surveyors had to contend against naturally ır progress very slow. . . for a path had to be cut through :hwood which choked up the narrow passage, and every tracting the vision of the levelers had to be felled.

cam had to be crossed over and over again . . . many a was saved our men on foot being able to cross over the 'es which, having been felled by . . . [beaver], *and had fallen ! the stream.*

ʻlapa Creek and Canyon, a proposed Wilderness Area iministered by the U.S. Bureau of Land Management and the George Whittell Wildlife Reserve of the lers of Wildlife, is one of the few southwestern ıs retaining a relatively pristine flora and fauna kley, 1981).

The lowermost Colorado River also had dense and extensive riparian vegetation. Pattie (1833) traveled there after descending the Gila River to its mouth:

. . . *Red* [Colorado] *river* [just above the inflow of the Gila River] . . . *is between two and three hundred yards wide, a deep, bold stream, and the water at this point is entirely clear. The bottoms are a mile in general width, with exceedingly high, barren cliffs. The timber of the bottoms is very heavy, and the grass rank and high. Near the river are many small lakes, which abound in beavers* [February, 1826; p. 99].

The [Colorado] *river, below its junction with the Helay is from 2 to 300 yards wide, with high banks. that have dilapidated by falling in. Its course is west, and its timber chiefly cotton-wood, which in the bottoms is lofty and thick set* [December 1828; p. 139] [Pattie and his trapping party began to float through the Colorado River Delta on 9 December, 1828].

[60 or 70 miles downstream] *we find the timber larger, and not so thick* [p. 143].

[about 100 miles downstream] *The river seems here to run upon a high ridge, for we can see from our crafts a great distance back into the country, which is thickly covered with mosquito and other low and scrubby trees* [p. 149].

Figure 4A. *Laguna Damsite, California, 26 July 1906; note continuous riparian zone of Fremont cottonwood and willows. U. S. Bureau of Reclamation. Photograph 115-P-35-303-9A.*

Aldo Leopold (1949) provided essentially the same descriptions of the Colorado River Delta when he and his brother canoed and hunted that region in 1922.

Sykes (1937) presented an authoritative review plus original data and photographs of the Delta prior to closure of Hoover Dam, some of which pertain to large organic debris. A 1746 diary recording entry into the Colorado River mouth by Father Ferdinand Konscak (translated by Monsignor M. D. Krmpotic; Sykes, 1937: 11) described the west side as:

> The side of California, lying low, is overflowed by [the] Colorado so that all along the foot of the mountains one sees pieces of trees, weeds, and the like left there by the water.

Lieutenant R. W. H. Hardy also recorded the California shoreline as low, flat, and covered with driftwood in 1926 (Sykes, 1937:14); it remained so near the turn of the Century (Fig. 6).

Major Heintzelman, Commander of Fort Defiance at the junction of the Gila and Colorado rivers, boated south to near the Colorado River's mouth in 1851 to meet the U.S. Schooner Invincible, which was on reconnaissance at the head of the Gulf of California. He noted in a letter to the San Francisco Daily Herald (22 October, 1951; Sykes, 1937: 24):

> The river bottom is several miles wide and covered with willow, cottonwood and mesquite, with the usual *underwood* and grass. From the junction [of the Gila and Colorado rivers] . .. the [Colorado] river is from *200* to *250* yards wide; below it varies from ½ to 1¼ mile between the banks—generally less than a mile. . . At the low stage the water seldom covers more than half this space, and frequently not *200* yards, the channel crossing and recrossing the bed in the most capricious manner; the whole width being filled with shifting sand. .. There are but few snags.

With reference to later operations of streamers on the lower Colorado River, Sykes (1937:32) wrote that:

> Kedging or warping [of river boats] by means of trees and stumps ashore was at times necessary in making bends and crossings. . .
>
> Snags were never very much of a menace or impediment to navigation. The heavier pine, cedar, or mountain-oak trunks which come down stream from the upper basins of the river system at every period of high water, are generally smoothed and water-worn into mere floating fragments by their long journey through the canyons and do not lodge readily. The lower basins furnish

Figure 4B. Laguna Dam, California, ca. 1975; agriculture has replaced the river and its riparian forests. Photograph by R. D. Ohmart.

'e vegetal debris of any size, and the willow and cotton- plings which grow so profusely upon certain portions of iplain are light and decay quickly.

ite the last statement, Sykes (1937:51) indicated stributary cuts on the delta produced significant :s of debris. Such was described in 1902 near the mouth:

les of recent drift matter, principally young willow and rees . . . had stranded along the sides . . . several small Df *drift matter—wood refuse, brush, tules, and the like— ..ere found stranded upon the flats about the mouth of the* River], *were followed down the estuary upon the first of tide at the "pre-spring" tidal period and were found to n their identity as units to the river mouth.*

sion

d on historic accounts, we conclude that substantial its of vegetative debris were available to streams of loran Desert. Presence of large amounts of wood in s is, however, not directly documented since a data om navigational records is scarcely available for the • Only the lowermost Colorado River was navigable am-powered boats. The Gila River from about the site of present-day Phoenix to its mouth was passable only by shallow-draft barges that were pulled from along the banks or drifted with currents.

Fate of Large Wood in desert Systems. Molar action of streams passing through canyons quickly reduces large logs and branches to smaller particles (Sykes, 1937). (Note that bark is absent from all woody debris in Figure 6 and that ends are consistently rounded). This may have been a major factor in the reported scarcity of large debris such as snags in desert reaches of Southwestern streams. Forbes (1902) commented on particulate organics in Arizona floodwaters as follows:

The flood waters are rich in organic matter swept by the rains from the earth's surface into the drainage. The microscope shows broken-down animal and vegetable matter abundantly in these waters [Salt River, central Arizona; p. 160).

His interests were principally in the "fertilizing qualities" of these materials, and he wrote further (p. 161):

This [fertilizing] value is in large part derived from dead vegetable and animal matter, especially the manure of grazing animals which accumulates on the ranges during a dry time, and then is

Figure 5. Above.—Colorado River below Yuma, Arizona, 1898; photograph from Southwest Museum, Los Angeles, California. Below.—Same vicinity, ca. 1975. Photograph by R. D. Ohmart.

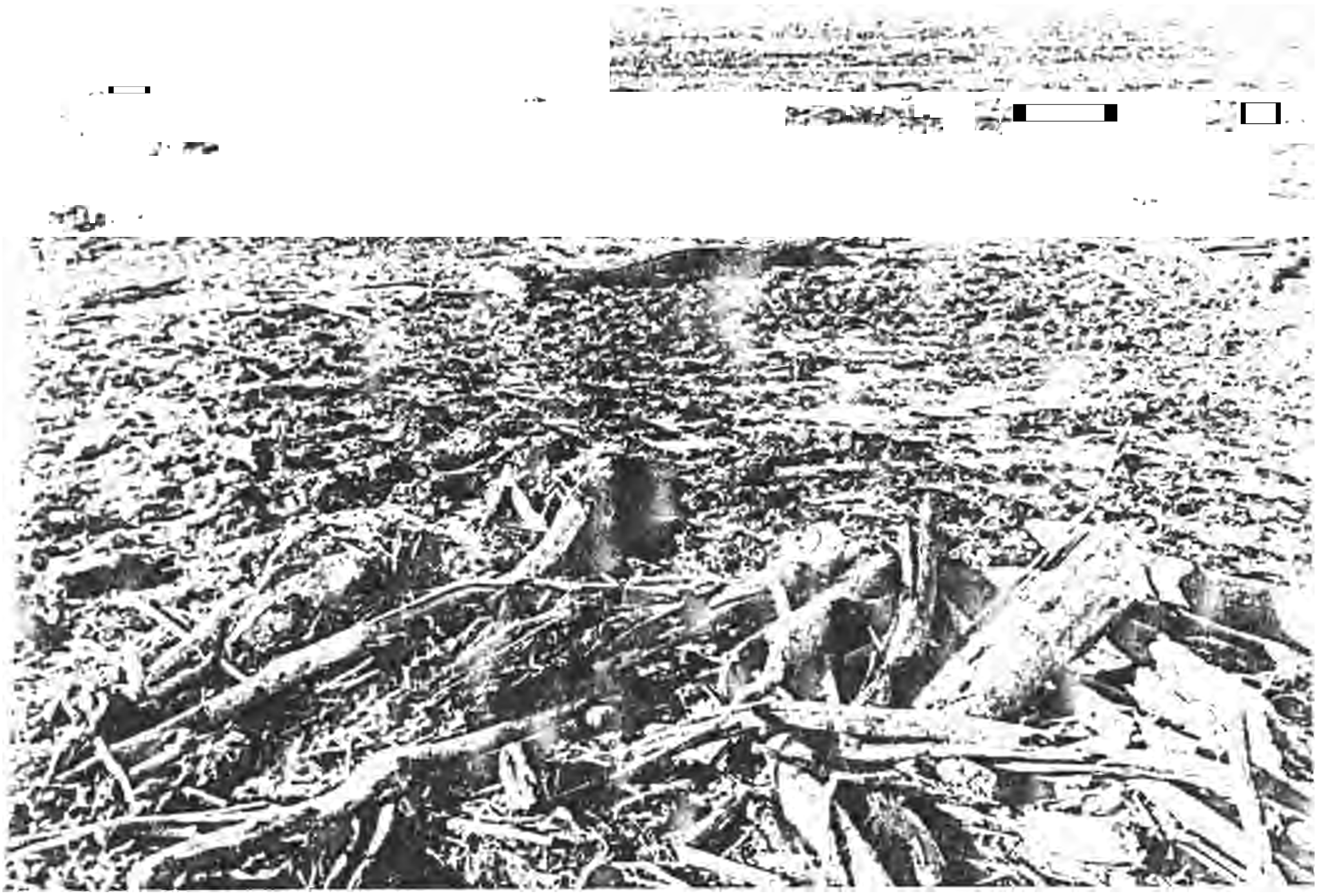

Figure 6. Debris piles on the Colorado River Delta, Mexico, near the turn of the century. Photograph from the MacDougal Collection, Arizona Historical Society, Tucson, Arizona.

often visibly carried into the drainage by the sudden floods characteristic of the Southwest. The stench of the first flood waters after a rain is due to decaying materials of this character, and it is not impossible that the peculiar faint "desert smell," usually perceptible far in advance of an approaching storm, is due to the same cause.

The volume of these materials was indicated by Sykes' ,1937) determination that near 8% (by weight) of flocculent muds deposited on the Colorado River Delta was organic matter (see also McGee, 1897 and Fisher and Minckley, 1978).

Morphometry of stream courses in low deserts, narrow canyons alternating with broad alluvial valleys, also influences transport and accumulation of large debris. Stream waters and transported materials accelerate through nigh-gradient canyons, then abruptly slow as water spreads over and percolates into alluvial fill of broader reaches Logs and other large debris thus accumulate on floodplains at the outlets of canyon segments, where they may remain to decompose in terrestrial habitats for months or years until transported by later flooding events. Emory (1848: 77) described the Gila River floodplain just downstream from inflow of the San Pedro River as:

It is principally of deep dust and sand overgrown with cotton wood, mesquite chamiza, willow, and the black willow. In places there are long sweeps of large paving pebbles. filled up with drift wood, giving the appearance of having been overflowed by an impetuous torrent.

Sporadic transport also is characteristic of ephemeral watersheds (Burkham, 1976a). Flash flooding often is absorbed by coarse alluvium, stranding organic materials upon, and incorporated within, sand-gravel-boulder substrates. Molar action and activities of terrestrial decomposers reduce these materials, so that only small particles arrive at receiving streams (Bruns and Minckley, 1980). These particles are an important food of aquatic invertebrates, particularly when algae are sparse during the first few days following recession of floods (Minckley, 1981; Fisher et al., 1982).

Such is not always the case. As in other regions (Anderson and Sedell, 1979), headwater streams may be blocked by logs and other debris at any elevation, and large debris is a major factor in development and maintenance of heterogeneity in the distinctive *ciénega* (riparian marshland) habitat along creeks of desert grasslands of Arizona (Hendrickson and Minckley, 1984). Log darns also have been recorded on the mainstream Gila River that persisted long enough to result in substantial channel and floodplain aggradation (Kipple, 1977). The role of drifting logs and other large organic debris in promoting destructive channel alterations and vast variations in instantaneous discharge during floods was described for the Gila River by Burkham and Dawdy (1970) and Burkham (1976b). Massive accumulations of logs and other large debris in mainstream reservoirs of central Arizona (Rinne, 1973, Minckley in Rinne, 1975) further attest to substantial volumes of such materials, now trapped in reservoirs, that formerly were available to downstream reaches. Decomposition of these vast amounts of woody material in reservoirs must be a major factor in their ecology (Rinne, 1975), a feature of these systems that is yet to be studied.

A major difference between inputs of large materials to Southwestern streams and those to rivers of better-watered zones is thus the markedly sporadic nature of floodflows in the desert systems. Rainfall that produces runoff of volume and duration sufficient to transport large debris may occur only one or a few times a decade (Rinne, 1975). Large litter, which scarcely decomposes in the arid Southwest except through actions of arthropods, thus accumulates on dry surfaces (McConnell, 1968), and is available for massive, almost instantaneous, movement into freshwater aquatic systems, and must have been a major nutrient input to the semi-isolated Sea of Cortez. Impacts of damming of the Colorado River on marine resources of Mexico have not been assessed (Thompson et al., 1979).

Functions of Large Debris in Desert Stream Systems. Three obvious functions of large particles in desert streams are: (1) their decomposition products that augment nutrient supplies; (2) organic materials are directly used as food by various biotic elements; and (3) a quasi-stable substrate is provided in these otherwise unstable systems (Anderson and Sedell, 1979).

The first aspect has yet to be studied in low-desert stream habitats, and may be important if nutrients are limiting. It seems likely that processes in hot waters of the Southwest might be far faster than elsewhere, and that unique chemical features of some aquatic systems (Cole, 1963; 1968) may provide variation on patterns of other regions.

Few invertebrates inhabiting hot-desert streams have adopted the trophic strategy of direct utilization of larger particulate materials. Wood is a low quality food source when initially submerged. With microbial processing woody debris becomes more palatable, and the microbial community contributes additional food to consumer organisms (Bird and Kaushik, 1981). Passive decomposition rates are, however, on the order of years for submerged wood, and for large logs centuries may be required (Swanson et al., 1976). Adaptations of invertebrates for direct utilization of wood include features not compatible with low-desert stream habitats. Long life cycles and low metabolic rates, for example, are characteristic of wood feeders, whereas most desert streams fluctuate so violently that short life cycles and rapid turnover have apparently been selected for (Gray, 1980, 1981). Active deterioration of large wood by molar action, as noted before, reduces particle size and makes the material more suitable for use by invertebrate detritivores.

Solid substrates are at a premium in most desert streams, and transport of unstable bedload has been cited as a major factor influencing invertebrate populations in most such streams yet studied in the region (Minckley 1979a-b, 1981; Bruns and Minckley, 1980; Gray, 1980, 1981). Shifting sand bottoms in desert streams, as elsewhere (Hynes, 1972), are essentially devoid of invertebrates (see, however, Edmonds and Musser in Dibble, 1960). Logs, twigs, and other larger materials may, however, be colonized by a diversity of species (Dibble, 1959, 1960; Parson et al., 1968; Ward et al., 1982).

Large debris also provides obstructions to flow, which results in formation of transitory, pool-like habitat in streams where water depths of more than a few centimeters may not otherwise occur (Minckley, 1981). Such obstructions and the resulting pools also retain organic materials, allowing for longer retention and processing times within the system. Concentration of drifting organic particles also enhances direct utilization of these materials by fishes and invertebrates as food. Fishes actively seek such places, not only for food and for cover afforded by the debris and greater depth of water, but also likely in the Southwest for shade from intense solar radiation. "Pools" induced by such obstructions may also intersect interflow of cooler water through porous substrates providing some amelioration of local summer water temperatures, which may otherwise reach lethal levels (Deacon and Minckley, 1974).

A Hundred Years of Change. A large percentage of southwestern riparian communities, especially at low elevations, have now been replaced by introduced saltcedar *(Tamarix chinensis).* This aggressive plant arrived along the Colorado River in the early 1900s, and has created a scenario of environmental change far beyond the scope of the present paper. Christianson (1962), Horton (1964, 1977), Robinson (1965), Babcock (1968), Haase (1972), Turner (1974), Ohmart et al. (1977), Graf (1978), and Turner and Karpiscak (1980) have reviewed the breadth and magnitude of invasion and spread of this pest.

Reductions in all riparian communities in the desert west is, however, an even greater problem. Direct destruction through woodcutting, agricultural development, urbanization, or the more subtle impacts of desiccation from stream incision, impoundment, and channelization, or over-grazing by livestock, has stimulated a recent surge of concern for these vanishing habitats (Carothers et al., 1974; Turner, 1974; Carothers and Johnson, 1975; Lacey et al., 1975; Cooke and Reeves, 1976; Hubbard, 1977; Johnson and Jones, 1977; Sands, 1977; Turner and Karpiscak, 1980; Minckley and Clark, 1981; Ohmart and Anderson, 1982; Minckley and Brown, 1982; Hendrickson and Minckley, 1984).

Fuelwood requirements for steamboats operating on the lower mainstream (Sykes, 1937, 1937; Fig. 7), and woodcutting for mining development and other energy demanding industries in the region (Hastings and Turner, 1965) had an early and severe impact on Colorado River riparian communities. Changes in world oil conditions in the past decade have again caused woodcutting, now for domestic purposes, to heavily influence riparian communities of the desert Southwest.

Clearing for agriculture also is a major factor in the de-

Figure 7. Cocopa Indian woodcutters and wood stacked for use in river steamboats. Downstream from Yuma, Arizona, 1887. Photograph from the Rodolph Collection, Bancroft Library, University of California, Berkeley, California.

cline of riparian and floodplain vegetation. In the Salt River Valley, central Arizona, cleared and irrigated agriculture land was increased from less than 200 hectares near the time of settlement in 1862 to many thousands of hectares in 1982. In the same period, the population of the Phoenix Metropolitan Area grew from 100 Anglo-American settlers to more than a million urban dwellers (Johnson, 1978). Dams constructed to provide irrigation and domestic water not only trapped essentially all particulate materials from the Salt River watershed, but also diverted the entire river for human use (Marsh and Minckley, 1982).

Cessation of flow in the river channels obviously resulted in vast changes in much of the riparian vegetation (Bryan, 1928), and pumpage to augment canal flow and the overall water supply further depressed underground waters so that even deep-rooted plants such as Mesquite were destroyed. Lining of canals with concrete further curtailed seepage, and use of herbicides in the past few decades to actively suppress phreatophytes for water conservation further decimated remaining riparian communities.

In more remote areas, over-grazing resulted in substantial degradation of watersheds (Haskett, 1935; Barnes, 1936; Wagoner, 1952, 1960), which contributed to incision of watercourses (Ohmart and Anderson, 1982). This resulted in water table declines in headwaters and at intermediate elevations, stimulating vast changes in riparian communities from shallow-rooted, water-loving species such as cottonwood and willows, to deep-rooted Mesquite, and ultimately to scrubland and other desert fasciations.

Future Patterns. Riparian habitats are being increasingly recognized as important components of Southwestern ecosystems, not only by the scientific community, but also by governmental and private agencies (Dick-Peddie and Hubbard, 1977; Pase and Layser, 1977; Brown, 1978). Revegetation is being accomplished along the Colorado River under the auspices of the U.S. Bureau of Reclamation (Anderson et al., 1978; Ohmart and Anderson, 1982), and impacts of grazing (Carothers, 1977; Davis, 1977) are being locally alleviated by fencing and herd rotation. Direct impacts of man's recreation on riparian communities are at least being evaluated (Aitchison, 1977), and claims of water conservation through vegetative clearing or "phreatophyte control" are being questioned (Ohmart and Anderson, 1982). Remnants of riparian communities, such as the Av-avaipa Canyon A[illegible]a (BLM, Defenders of Wildlife), Sonoita Creek Sanctuary, and Canelo Cienega (Nature Conservancy), and possibly the San Pedro River by a consortium of State, private, and Federal agencies (McNatt, 1978), are being preserved. The Arizona Natural Area Program identified many such places for recognition and preservation (Smith, 1974; Bergthold, 1978). The U.S. Forest Service has an active riparian study and preservation program through its Fores[illegible]ange Experiment Stations, and the U.S. Fish and Wildlife Service maintains an active Riparian Study Group in the region (McNatt, 1978). Problems are thus being recognized, research and preservation are underway, and at least parts of the riparian and associated ecological systems in hot deserts may be perpetuated.

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