Desired future condition: Fish habitat in southwestern riparian-stream habitats

John N. Rinne[1]

Abstract.—Riparian ecosystems in the southwestern United States provide valuable habitats for many living organisms including native fishes. An analysis of habitat components important to native fishes was made based on the literature, case histories, and unpublished and observational data. Results suggest a natural, surface water hydrograph and lack of introduced species of fishes being the two most critical habitat components delimiting sustainability of native fishes in the Southwest. Vegetation, channel characteristics and instream hydrological features (i.e. depth, velocity, and substrate) are important in distribution and sustainability of native fishes but secondary to the first two and are more important or relevant as management activities affect them. Desired Future Condition for native southwestern fishes ultimately depends on proper or desirable functioning of riparian ecosystems.

INTRODUCTION

Riparian ecosystems comprise a small portion (< 2%) of the total southwestern landscape. Their ecological and natural resource value in this region is vastly disproportionate to their relative surface area. These critical habitats are very important to a host of living organisms, and essential for many. Beginning in the 1970s (Ames 1977, Johnson and Jones 1977) these areas increasingly have become the object of greater interest to researchers and land managers (Johnson et al. 1985, Arizona Game and Fish 1995). In Region 3, the Southwestern Region of the U. S. Forest Service, these areas are afforded priority management status (USDA 1992a).

Within the category of obligate riparian-stream inhabitants are native fishes (Minckley 1973, Sublette et al. 1990, Rinne and Minckley 1991). Although the native fish fauna is not diverse in the Southwest (< ca 40 species), by default, surface water reaches of riparian areas provide critical habitats for native fishes. Most of the Southwest landscape is arid and comprised of the Sonoran Desert (Dunbier 1970). Desert landscapes are designated or delineated by their lack of water. Paradoxically, fishes require the medium of water to sustain themselves and are very intimately linked to riparian-stream areas.

The objectives of this paper are to

- Define habitat components in southwestern riparian-stream areas that are important to and influence or legislate fish habitat and populations,
- Present data and published literature that illustrate the state of knowledge and discuss the relevance of these habitat components to fish habitat, and
- Discuss the concept of "Desired Future Condition" as it relates to fish habitat in southwestern riparian-stream areas.

[1] *Fisheries Research Biologist, Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona. Headquarters is located in Fort Collins, Colorado.*

KEY HABITAT COMPONENTS

Habitat components important to fishes are many, however, several physical and one biological factor are paramount. These are:

1. Water;
2. Riparian vegetation;
3. Nearstream features— streambanks, channel type and morphology;
4. Instream features —substrate composition and hydrological characteristics (e.g. width, depth, velocity, and gradient); and
5. Introduced species of fishes.

Water

Water is the controlling or driving component of all riparian ecosystems. The quantity and quality of this vital component in time and space is fundamental to fish habitat (Rinne 1991a, Heede and Rinne 1990) and distributions (Hubbs and Miller 1948). The vagaries of climate in the Southwest (Green and Sellers 1964) alone render extreme variability in quality and quantity of surface water in riparian areas. Variability is further accentuated by geological landscape features (Rinne in press a).

Annually, within a stream or given reach of stream in a brief (hours to days) time period, hydrology can range from presence of surface water, to intermittent pools, to lack of surface water, to raging torrents, and return to surface flow. Although native fishes appear to be uniquely adapted to these vicious cycles of habitat conditions (Minckley 1973, Deacon and Minckley 1974, Rinne and Minckley 1991, Rinne 1994, Stefferud and Rinne in press), none can sustain themselves once surface flow is totally lacking.

Because of arid climate, varying rainfall patterns, and topographic features (Rinne in press a), many channels and "arroyos" are ephemeral to intermittent throughout much of the year (Arizona Game and Fish Dept 1978). Most riparian areas containing naturally-flowing, perennial surface waters are associated with upper elevation (> 1,000 m) areas of the state. For example, rotometric measurement of surface area in the state of Arizona where most (> 95%) of the surface water is present suggests that about 10% of the landscape of the State contains most (95%) of the remaining naturally-flowing surface water. Most of these riparian stream systems lie along the Mogollon Rim in central Arizona.

Lower elevation (< 1000 m) mainstream rivers have been beheaded by numerous dams (Minckley 1973, Rinne 1991a, 1994, Rinne and Minckley 1991) and flow only intermittently or in a modified state (Arizona Game and Fish 1978). Other perennial streams in Arizona sustain base surface flow through effluents from municipal, industrial or agricultural effluents or spring sources. For example, the reach of the Salt River that passes through the greater Phoenix area once supported 15 species of native fishes (Minckley and Deacon 1968). Construction and closure of dams commencing with Roosevelt on the Salt River in 1911, followed by a series of subsequent, downstream dams on the Salt River, and two on the Verde completely dried this reach of river. Now only a host of introduced fishes persist in the intermittent surface water pools created by gravel mining operations and sewage effluents.

Natural hydrographs appear very important in sustaining native stream-dwelling fishes in the Southwest (Meffe and Minckley 1991, Rinne 1994, Rinne 1995b). Periodic flood events in southwestern rivers and streams appear to control or limit non-native fishes. Recent data from the Verde River suggest that both native and non-native fish populations are reduced by flooding, however, native populations quickly rebound (Stefferud and Rinne In Press) because of reproductive strategies adapted to post-flood events and stream channel habitat restructuring (Mueller 1984, Rinne 1995b). By contrast, reservoirs that alter and control the natural variability of southwestern river and stream hydrographs, favor the sustainability of introduced fishes.

Most of the above discussion relates to quantity of water and its relevance to fish habitat. Conceivably, quality of water should be an equally important component of fish habitat. There are few studies of water quality as they relate to fish habitat and native fish populations in the Southwest. Most species appear to survive in widely varying water quality conditions. Water temperatures in low desert riparian-stream systems may vary widely within a diel cycle and reach 30 degrees C or more (Deacon and Minckley 1974). Recent experiments indicate several native fishes sustain elevated heart rates under elevated water temperatures. Heart rates of 30-40 beats per minute in winter months at water temperatures of 15-20 C climb to twice that in the summer (unpublished data). Studies by Lee and Rinne (1980) indicate that the two native trouts in the Southwest do not succumb until water temperatures reach 29 degrees C. Other studies by Lowe et al. (1967) have examined dissolved oxygen requirements of several native species. Similarly, these species showed tolerance of a range of conditions.

The variability of water quality characteristics such as listed above is very great in time and space in the Southwest, often going from one extreme to another in a given reach of stream and often within a short (diel) time period. Therefore, research designed to determine the chronic effects of dissolved oxygen, turbidity and temperature may be of more academic than practical importance.

In summary, water is a precious commodity in the arid American Southwest. Water development has permitted ever-escalating ecomonic development of the region. The demand by humans for water alters flow regimes or completely removes from riparian-stream areas the most basic component of fish habitat—water. In a relative sense, the quantity of this habitat component and its natural variability in time and space are more important to native fishes than its quality.

Riparian vegetation

Woody vegetation within riparian-stream areas has been suggested as an important component of fish habitat. Woody streamside vegetation structure provides cover for fishes (Boussu 1954) and potentially shades stream habitats and reduces extremes of water temperature. Secondly, roots of woody vegetation stabilize streambanks and maintain their integrity in time and space. Thirdly, terrestrial insects occupying woody vegetation serve as a portion of the food source for fishes (Meehan et al. 1977). Finally, nearstream and streamside vegetation, once dead, produce "large woody debris (LWD)" to riparian stream systems.

Previously, herbaceous aquatic vegetation has not been considered an essential component of fish habitat. However, recent publications (Bridges et al. 1994.) and research being conducted by the Rocky Mountain Station, Flagstaff, Arizona, (Medina et al. in press) are implicating its importance to proper functioning of riparian-stream areas which, in turn, could be very important to fish habitat. However, the latter linkage or connection has not been substantiated.

LWD as a byproduct of riparian vegetation and as a component of fish habitat has been studied in great detail, albeit mostly in the Pacific Northwest (Meehan 1991, USDA 1992b). In the Northwest, the role of LWD as holding and rearing habitat for salmonids has been well-documented (Bryant 1983, Andrus et al 1988, Bisson et al 1982). The importance of LWD as fish habitat has also been demonstrated for both salmonids (Flebbe and Dolloff 1995) and selected warmwater species of fishes (Angermeier and Karr 1984) in the eastern United States. LWD has also been demonstrated to be important in structuring channel morphology (Keller 1979, Heede 1985, Cherry and Betscha 1989, Smith et al 1993, Richmond and Fausch in press). Only one of these studies (Heede 1985a) was conducted in the Southwest.

By comparison, the importance to fish habitat of live woody vegetation along riparian-stream corridors has not been unequivocally demonstrated in the Southwest. However, based on fish population estimates in two streams in the White Mountains, the contribution of Arizona alder (*Ulnus arizonae*) to Apache trout (*Oncorhynchus apache*) habitat and populations seems founded (Table 1). In two comparable streams lying alongside a contiguous ridge and less than two kilometers apart there appears to be a marked difference in trout density in reaches of stream having an alder component compared to those without streamside alder.

Table 1. Comparison of mean Apache trout density per kilometer of stream based on 40-m sample sections (n in parentheses) within vegetated and non-vegetated reaches of Boggy and Centerfire creeks, 1993-94.

	Vegetated		Un-vegetated	
Stream	1993	1994	1993	1994
Centerfire Creek	115 (22)	68 (14)	0 (16)	3.6 (7)
Boggy Creek	127 (13)	110 (16)	0 (9)	15 (13)

The function of LWD in providing habitat in form of cover or reduction of stream water temperatures or as a significant supplier of food likewise is undocumented. Rinne (1975) reported the probable importance of input of LWD into central Arizona reservoir ecosystems and Minckley and Rinne (1985) presented a historical review of LWD in the Southwest. Recently, Alexander and Rinne (in press) reported on the mobility of LWD in several streams impacted by a wildfire compared to one un-impacted stream. Rinne (1981) suggested that pools created by log stream improvement structures in several montane streams in southwestern New Mexico were of better quality and provided better fish habitat based on numbers, size, and biomass of Gila trout (*Oncorhynchus gilae*). However, 50% of these LWD structures artificially-imposed at right angles to flow were lost in flood events within a decade suggesting either design or more broad, watershed scale problems, or both.

The amounts of LWD in streams along a number of streams in the Mogollon Rim area of central Arizona and in the White Mountains of east-central Arizona is just beginning to be documented (Table 2). Compared to streams in the Pacific Northwest and northern Rocky Mountains (Richmond and Fausch In Press), montane streams in the Southwest have comparable amounts of LWD pieces per unit length of stream. Again, the role of LWD as fish habitat and the relationship to fish density and biomass in the Southwest is unstudied.

Table 2. Comparison of the variability of size classes of large woody debris in kilometer reaches of streams in the White Mountains of east-central Arizona and below the Mogollon Rim, central Arizona, 1995. Values are percentages of total. Size classes are: I = < 3 m X <0.15; II = > 3 m to 6 m X > 0.15 m to < 0.25 m; and III = > 6 m X > 0.25 m.

		Size Class		
	N	I	II	III
White Mountains				
Conklin	*298*	*55*	*32*	*13*
Bear	*303*	*62*	*25*	*13*
Double Cienega	*391*	*47*	*33*	*20*
Corduroy	*347*	*53*	*29*	*18*
Mamie	*529*	*56*	*29*	*15*
Coyote	*486*	*54*	*31*	*15*
Hanagan	*449*	*64*	*26*	*10*
Mogollon Rim				
Bray	*230*	*36*	*34*	*30*
Christopher	*185*	*30*	*42*	*28*
Webber	*439*	*41*	*40*	*19*
Horton	*162*	*43*	*48*	*9*
Tonto	*109*	*43*	*49*	*8*
Pine	*177*	*34*	*47*	*19*

Nearstream and instream features

Streambanks

Structure of streambanks and associated channel morphology may be important components of fish habitat. In first order upper elevation streams, undercut banks could serve as cover for native southwestern salmonids. Assessment of this physical feature can be made by bank angle measurements (Platts et al. 1987). Unstable streambanks can contribute extensive fine sediment to stream substrates and reduce establishment of both herbaceous and woody vegetation.

Stability of streambanks may be related to land management practices such as livestock grazing (Platts 1979, 1981, 1982, Rinne 1985) and timber harvest (Chamberlain et al. 1991). Both chiseling of streambanks by livestock hooves and logging roads crossing streams may induce "nick points" from which streambanks commence to unravel. Cooperative research between the Rocky Mountain Station, Apache Sitgreaves National Forest, and the Arizona Game and Fish Department on several streams in the White Mountains influenced by ungulate grazing is designed to define bank "damage" as influenced by ungulate grazing on first order streams.

Stream substrate

Substrate composition of a stream is a vital component of fish habitat. Fishes spawn on or the spawning products develop within stream substrates. Substrate composition is a product of parent geology, channel morphology, gradient, and watershed size and resultant stream hydrograph. The nature and amount of macroinvertebrates, the major food source for many native fishes, is dictated by stream substrate composition. The two native salmonids, Gila and Apache trout, spawn on gravel-pebble (8-32 mm) substrate (Harper 1978, Rinne 1982). The relative amounts and distribution of these materials in streams in Arizona and New Mexico conceivably could limit trout populations. Further, the fine sediment (< 2 mm) component of substrate materials could also limit successful reproduction. Laboratory studies of the effects of fine sediment content of substrate on Apache trout fry emergence suggest that with increasing fine sediments, successful emergence decreases. Based on preliminary experimentation, at fine sediment concentrations of 20 %, Apache trout fry emergence is reduced by 24% relative to controls. At 30 % fines, reduction is 75%.

Pure populations of the Apache trout occur in streams in the White Mountains of Arizona on the Apache-Sitgreaves National Forest and the Fort Apache Indian Reservation. Recent (1980s) stream surveys of trout numbers and biomass indicate that streams sampled on the Reservation support a much higher (5-10 times) biomass of Apache trout than did a suite of Forest streams. A priori, this could be attributed, in part, to either 1) limitation of adequate-sized substrate materials for spawning or 2) excessive fine sediment content in stream substrates within Forest streams. On the basis of preliminary analyses of available spawning gravels in substrates and fine sediment content in Forest and Reservation streams, it appears that availability of optimum spawning gravels may be limiting within streams on the Forest (Tables 3, 4).

Rearrangement and scouring of substrate materials by flood events is apparently important to spawning of non-salmonid fishes in the Southwest. Mueller (1984) documented artificial disturbance of substrate materials by heavy equipment in a stream in southwestern New Mexico stimulated massive spawning by the speckled dace (*Rhinichthys osculus*). Apparently, such disturbance simulated a flood event. Kepner (1982) reported longfin dace (*Agosia chrysogaster*) displayed multiple spawning in Aravaipa Creek, an upper Sonoran Desert stream in southeastern Arizona, synchronized with flood events. Observations on the upper Verde River, Prescott National Forest, suggest multiple spawning of the desert sucker (*Catostomus clarki*) in the summer of 1995 following winter (February) flood events.

Table 3. Fine sediment (< 2 mm; % by weight) and spawning substrate for Apache trout (4-16 mm; % by weight) in substrates of three streams on the Fort Apache Indian Reservation, September 1994. Ranges of data are in parentheses.

Stream	N	Fines (< 2mm)	Spawning (2-16 mm)
Ord Cr.	20	25 (8-42)	37 (25-51)
Pacheta Cr.			
Upper	12	14 (4-21)	43 (26-49)
Lower	8	25 (11-44)	27 (21-36)
Reservation Cr.			
Upper	9	22 (16-27)	40 (26-53)
Lower	9	28 (19-32)	48 (42-61)
Mean of 58 Samples		22.7	31.4%

Table 4. Comparison of frequency of occurrence of mean percent fine sediment (< 2 mm) in substrates of 30 streams (n = 402) and percent by weight of spawning gravels for Apache trout (4-16 mm) in 1) 10 streams on the Apache Sitgreaves National Forest and 2) at five sites in three streams on the Fort Apache Indian Reservation (n = 58).

Management area	Percentage Concentration Class 0-10	11-20	21-30	31-40	41-50	51-60
Forest						
fines	10	14	6	0	0	0
spawning[1]	6	4	0	0	0	0
Reservation						
fines	0	1	4	0	0	0
spawning[2]	0	0	12	23	16	7

[1]based on pebble counts

[2]based on sieve analyses of random substrate samples

Channel morphology

Channel morphology has been categorized by Rosgen (1994). Based on channel typing and probable associated instream and nearstream features, one could hypothesize which channel types might serve as higher quality fish habitat. However, no information are available on the relative quality of fish habitat afforded by differing channel types. This is an area that needs research. Medina and Martin (1985) reported dramatic changes in channel morphology of Mcknight Creek resulting from a wildfire on its watershed 50 years previous. Populations of Gila trout appear to be affected by the combination of flood events and channel degradation (Rinne in press c).

Hydrologic features

Width, depth and velocity of water in riparian-stream systems are important to fish habitat. Because water is the medium in which fish spend all their life, respective species select different combinations of these aquatic habitat characteristics to reproduce, feed, and rest or hide in (Heede and Rinne 1990, Rinne 1988, 1989, 1991a, 1994). The Gila trout for example has been labeled a pool dweller in headwater streams in southwestern New Mexico (Rinne 1978). Although the seven native species of fishes in Aravaipa Creek overlap and utilize similar physical habitats, they partition niches based on food supply (Rinne 1992, 1995b). Recent study of a native fish community on the upper Verde River indicates consistent capture of respective species in the same habitat velocities (i.e. high and low gradient riffles, glides, runs, and pools; unpublished data) over a 60-km reach of river.

Velocity of water is controlled largely by stream gradient. Substrate composition, in turn, is a result of velocity of water. The interactions of these habitat features work in combination to legislate fish habitat, distributions and populations. Some native fish species appear to be limited in distribution by stream gradient. The Little Colorado spinedace appears to move downstream readily when placed in higher gradient (> 3%) streams (Rinne In press b). Similarly, the Rio Grande sucker (*Catostomus plebeius*) is not distributed in reaches of streams in northern New Mexico that have gradients greater than 3% (Bob Calamusso, pers comm.).

Introduced fishes

A primary biological influence on aquatic habitats and their suitability for native fishes is the presence or absence of introduced, non-native fishes. Numerous case history studies, observational data and the published literature (Meffe 1985, Minckley and Deacon 1991, Blinn et al. 1993, Douglas et al. 1994, Rinne 1990, 1994) combined with more recent laboratory studies (Rinne and Alexander in press) indicate that the presence of non-native fishes is perhaps a dominant factor over physical habitat in delimiting native fish distributions. Through the mechanisms of predation, hybridization, and competition acting singularly or in combination , non-native fish species effectively replace native species (Rinne 1994). As indicated above, replacement is further facilitated by damming of riparian-stream areas and altering natural hydrographs, reducing variability in flows and stability of aquatic habitats.

DESIRED FUTURE CONDITION AND FISH HABITAT IN RIPARIAN HABITATS

As an alternative , one could change the terminology for the "F" of the acronym DFC or "desired future condition" to effect the concept of "desired fisheries condition." A modification of the concept is in agreement with "Desirable Functioning Processes" proposed by Medina et al. (this issue) and "proper functioning condition" by Bridges et al. (1994). Considering both, riparian-streams systems must be properly functioning hydrologically, biologically and physically in order to provide optimum fish habitat for native fishes. Accordingly, I will rank or prioritize the above-discussed habitat features into a working, functioning context that will sustain native fishes in southwestern riparian-stream ecosystems.

Of first priority, is surface water quantity. In absence of this fish habitat component, the other factors are rendered irrelevant. Because of the obligatory relationship of fish to surface water this habitat factor is of number one priority. Any management activities that contribute to or in themselves effect reducing flow to subsurface levels for even a brief period of time must be avoided. Unfavorable water quality may come as a result of reduced flow, but many native species often will survive these harsh, unfavorable conditions until the next spate replenishes surface flow. Nevertheless, water quantity is of greater importance than is water quality as a limiting fish habitat factor. Instream flow designation and purchase of water rights are two viable strategies to insured surface water for fish habitat. However, instream flow consisting of a natural hydrograph is preferrable over sustained "minimum flows."

Introduced fishes are the next most important limiting factor to viable native fish habitat. If absent from reaches of streams or entire watersheds or stream systems, all effort should be made to prevent entry of non-native fish species. If present, land managers should be vigilant of opportunities to remove them from these systems. Removal of non-native salmonids has been done very successfully with Apache and Gila trout management in montane streams in the Southwest (Rinne et al. 1981, Rinne and Turner 1991). Removal of non-native fishes becomes more difficult as one moves downstream into larger riparian-stream ecosystems and into reaches of greater habitat complexity and variable watershed ownership and uses. In these larger riparian-stream systems such as the upper Verde, Salt and Gila rivers, a natural hydrograph is the primary factor that will effect maintenance of native fish habitat by periodic reduction of non-native fish populations.

Another management alternative is to designate watersheds for native fish management and others for introduced, primarily sport fish management (Rinne and Janisch 1995). The designation of the upper West Fork of the Black River on the Apache Sitgreaves National Forest is a primary example of this management strategy. Artificial fish barriers (Rinne and Turner 1991) are often required to effect such conservation efforts, unless natural barriers are present. Sustaining the absence of non-natives or removal of these species if present, superimposed upon maintenance of surface waters is probably 80-90% of the battle in providing suitable habitat for southwestern native fishes inhabiting riparian-stream ecosystems.

The remaining contribution to establishing, maintaining, or enhancing other fish habitat factors discussed above will come through proper land management (Rinne 1990). All management must be done in the context of the watershed as being a major effector of riparian habitat structure and function (Platts and Rinne 1985, Debano and Schmidt 1989, Rinne 1990, Reid 1994). The linkages between the watershed and the riparian area, between riparian form and structure and fish habitat must be addressed in future research (Likens and Borman 1974). Ultimately, the linkage between fish habitat and fish populations must be defined and modeled. However, based on the efforts of Fausch et al. (1988) modeling may be very difficult and if accomplishable, will only be achievable at a local or regional scale. Clarkson and Wilson (1995) evaluated a suite of habitat variables measured through the General Aquatic Wildlife methodology and Habitat Condition Indices for three dozen streams in the White Mountains of Arizona. Results suggest that relating and predicting fish populations and biomass by habitat factors, if accomplishable at all, will be only on a local or regional basis scale.

ACKNOWLEDGMENTS

The White Mountain Apache Tribe is gratefully acknowledged for granting permission to collect sediment samples on Reservation streams. Kelly Meyer of the Tribal Fish and Wildlife Department is specifically acknowledged for field assistance.

LITERATURE CITED

Alexander, M. M. and J. N. Rinne. in press. The effects of wildfire on southwestern riparian-aquatic ecosystems: Large woody organic debris. *In*, Hydrology and Water Resources in Arizona and the Southwest 17. Arizona Sect., Amer. Water Resour. Assoc., Hydrol. Sect. AZ-NV Acad of Sciences, and The Ariz. Hydrol. Soc. Northern Arizona University, Flagstaff Arizona.

Ames, C. R. 1977. Wildlife conflicts in riparian management: Grazing. *In*, R. R. Johnson, and D. A. Jones (tech. coord.), Importance, Preservation, and Management of Riparian Habitat. USDA For. Serv. Gen. Tech. Rep. RM-43:39-51. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Andrus, C.W., B.A. Long, and H.A. Froehlich. 1988. Woody Debris and Its Contribution to Pool Formation in a Coastal Stream 50 Years after Logging. Canadian Journal of Fish and Aquatic Science 45:2080-2086.

Angermeier, P.L. and J.R. Karr. 1984. Relationships Between Woody Debris and Fish Habitat in a Small Warmwater Stream. Transactions of the American Fisheries Society 113:716-726.

Arizona Game and Fish Department. 1978. Drainage Map of Arizona showing Perennial Streams and some Important Wetlands. Ariz. Game and Fish Dept., Phoenix, Ariz.

Arizona Game and Fish Department. 1995. Proceedings of the Tonto National Forest Aquatic and Riparian Ecosystem Workshop. Mesa, Arizona, April, 1995.

Bisson, P.A., J.A. Nielsen, R.A. Palmason, and L.E. Grove. 1982. "A system of Naming Habitat Types in Small Streams with examples of Habitat Utilization by Salmonids During Low Streamflow", in Armantrout, N.A. (Ed.). Acquisition and Utilization of Aquatic Habitat Inventory Information, American Fisheries Society, Western Division, Symposium Proceedings, Portland, Oregon, 62-73.

Blinn, D. W., C. Runck, D. A. Clark, and J. N. Rinne. 1993. Effects of rainbow trout predation on Little Colorado spinedace. Trans. Amer. Fish. Soc. 122: 130-143.

Boussu, M. F. 1954. Relationship between trout populations and cover of a small stream. J. Wildl. Mange. 18(2): 229-239.

Bridges, C., W. Hagenbuck, R. Krapf, S. Leonard, and D. Prichard. 1994. Riparian area management: Process for assessing proper functioning condition for lentic riparian-wetland areas. USDI Bur. of Land Management Tech. Rept. WRP-1737-11., Denver, Colo.

Bryant, M. 1983. The Role and Management of Woody Debris in West Coast Salmonid Nursery Streams. North American Journal of Fisheries Management 3:322-330.

Chamberlain, T. W., R. D. Harr, and F. H. Everest. 1991. Timber harvesting, silviculture, and watershed processes, pp- 181-206. *In*, W. R. Meehan (ed.) Influences of Forest and Rangeland Management on Salmonid Fishes and their Habitats.

Cherry, J. and R.L. Beschta. 1989. Coarse Woody Debris and Channel Morphology: A Flume Study. Water Resources Bulletin 25(5):1031-1036.

Clarkson, R. W., and J. R. Wilson. 1995. Trout biomass and stream habitat relationships in the White Mountains area, east-central Arizona. Trans. Amer. Fish. Soc. 124(4): 599-612.

Deacon, J. E. and W. L. Minckley. 1974. Desert fishes, pp 385-488. *In*, G. W. Brown Jr. (ed.) Desert Biology. Vol 2. Academic Press.

DeBano, L.F. and L.J. Schmidt. 1989. Improving southwestern riparian areas through watershed management. United States Department of Agriculture, Forest Service, General Technical Report RM-182. p. 1-33.

Douglas, M. E., P. C. Marsh, and W. L. Minckley. 1994. Indigenous fishes of western North America and the hypothesis of competitive displacement: *Meda fulgida* (Cyprinidae) as a case study. Copeia 1994(1): 9-19.

Dunbier, R. 1970. The Sonoran Desert. Its geography, economy, and people. Univ. Ariz. Press. Tucson, Arizona. 426 pp.

Flebbe, P. A. and C. A. Dolloff. 1995. Trout use of woody debris and habitat in Appalachian Wilderness streams of North Carolina. N. Amer. J. Fish. Manage. 15(3): 579-590.

Green, C.R., and W.D. Sellers (editors). 1964. Arizona climate. University of Arizona Press, Tucson. p. 503.

Harper, K. C. 1978. Biology of a southwestern salmonid, *Salmo apache* (Miller 1972), pp. 99-111. In, J. R. Moring (ed.) Proc. Wild Trout-Catchable Trout Sympos., Eugene, Oregon, February 15-17, 1978.

Heede, B. H. 1985. Interactions between streamside vegetation and stream dynamics. USDA Forest Service, General Technical Report RM 120: 54-58.

Heede, B. H. and J. N. Rinne. 1990. Hydrodynamics and fluvial morphologic processes: Implications for fisheries management and research. N. Amer. J. Fisheries Manage 10: 249-268.

Hubbs, C.L., and R.R. Miller. 1948. Correlation between fish distribution and hydrographic history in the desert basins of western United States. Bulletin University of Utah 38(20):18-166.

Johnson, R. R. and D. A. Jones, (tech. coords.). 1977. Importance, preservation and management of riparian habitat: A symposium. USDA For. Serv. Gen. Tech. Rep. RM-43: 1-217. Rocky Mtn. For. and Range. Exp. Sta., Fort Collins, Colo.

Kepner, W. 1982. Reproduction biology of longfin dace, *Agosia chrysogaster*, in a Sonoran Desert Stream. Unpubl. M.S. Thesis, Arizona State Univ.

Keller, E.A. and J. Swanson. 1979. Effects of large organic material on channel form and fluvial processes. Earth Surface Processes 4: 361-380.

Lee, R. M. and J. N. Rinne. 1980. Critical thermal maxima of five trout species in the southwestern United States. Trans. Am. Fish. Soc. 109: 632-635.

Likens, G. E. and F. H. Bormann. 1974. Linkages between terrestrial and aquatic ecosystems. Bioscience 24(8): 447-456.

Medina, A.L. and C. Martin. 1988. Stream channel and vegetation changes in sections of Mcknight Creek, New Mexico. Great Basin Naturalist 48(3):373-381.

Medina, A. L., M. B. Baker, and D. G. Neary. 1996. Desirable functional processes: A conceptual approach for evaluating ecological condition *In* USDA Forest and Range Experiment Station, General Technical Report, Fort Collins, CO, this issue.

Meehan, W. R. (Ed.). 1991. Influences of forest and rangeland management on salmonid fishes and their habitats. Amer. Fish. Soc. Spec. Publ. 19:1-751.

Meehan, W. R., F. J. Swanson, and J. R. Sedell. 1977. Influences of riparian vegetation on aquatic ecosystems with particular reference to salmonid fishes and their food supply, pp. 137-145. *In*, R. R. Johnson and D. A. Jones (tech. coordinators) Importance, preservation and management of riparian habitat: a symposium. USDA Gen. Tech. Rep. RM-43, Fort Collins, Colorado.

Meffe, G. K. 1985. Predation and species replacement in American southwestern fishes: a case study. Southwest. Naturalist 30: 173-187.

Meffe, G. K. and W. L. Minckley. 1987. Persistence and stability of fish and invertebrate assemblages in a repeatedly disturbed Sonoran Desert stream. Amer. Midl. Nat. 117(1): 177-191.

Minckley W.L. and J.E. Deacon. 1968. Southwestern fishes and the enigma of "endangered species". Science. 159: 1424-1432.

Minckley, W.L. and J.N. Rinne. 1985. Large Woody Debris in Hot-Desert Streams: An Historical Review. Desert Plants 7(3): 142 153.

Minckley, W. L. and J. E. Deacon. 1991. Battle against extinction: Native fish management in the American West. Univ. Ariz. Press, Tucson. 517 pp.

Mueller, G. 1984. Spawning by *Rhinichthys osculus* (Cyprinidae) in the San Francisco River, New Mexico. The Southwestern Naturalist 29:354-356.

Platts, W. S. 1979. Livestock grazing and riparian-stream ecosystems: An overview, p. 39-45. *In*, O. B. Cope (ed.), Grazing and riparian-stream ecosystems: A forum. Trout Unlimited, Inc.

Platts, W. S. 1981. Effects of sheep grazing on a riparian-stream environment. USDA For. Serv. Res. Note INT-307: 1-6. Intmtn.. For. and Range Exp. Stn., Ogden, Utah.

Platts, W. S. 1982. Livestock and riparian fishery interactions: what are the facts? Trans. N. A. Wildl. and Nat. Res. Conf. 47: 507-515.

Platts et al. 1987. Methods for Evaluating Riparian Habitats With Applications to Management. General Technical Report INT-221:83-93.

Platts, W.S. and J.N. Rinne. 1985. Riparian and stream enhancement management research in the Rocky Mountains. North American Journal of Fisheries Management 5:115-125.

Reid, L. M. Research and cumulative watershed effects. USDA Forest Service Gen. Tech. Rept. PSW-141: 1-118.

Rinne, J. N. 1975. Hydrology of the Salt River and its reservoirs, central Arizona. Jour. Ariz. Acad. Sci. 10(2):75-86.

Rinne, J. N. 1978. Development of methods of population estimation and habitat evaluation for management of the Arizona and Gila trouts. *In*. John R. Moring, (ed.), Proc. Wild Trout - Catchable Trout Symposium, Eugene, Ore., Feb. 15-17, 1978.

Rinne, J. N. 1981. Stream habitat improvement and native southwestern trouts. USDA, For. Serv. Res. Note RM-409: 1-4.

Rinne, J.N. 1982. Movement, home range, and growth of a rare southwestern trout in improved and unimproved habitats. North American Journal of Fisheries Management 2:150-157.

Rinne, J. N. 1985. Livestock grazing effects on southwestern streams: A complex research problem, pp. 295-299. *In* Johnson, R. R. et al. (tech eds). Proc. First North American Riparian Conference. Riparian ecosystems and their management: reconciling and conflicting uses. USDA For. Serv. Gen. Tech. Rep. RM-120:1-523.

Rinne, J. N. 1989. Minimizing grazing effects on riparian stream habitats: Recommendations for research and management, pp 15-28. *In*, G. Flock (ed), Proc. National Sympos. for Enhancing States/Wetland Management Programs. North American Lake Management Society, Chicago, Ill. May 1989.

Rinne, J. N. 1989b. Physical habitat use by loach minnow, *Tiaroga cobitis* (Pices: Cyprinidae), in southwestern (USA) desert streams. Southwestern Nat. 34(1):109-117.

Rinne, J.N. 1990. The utility of stream habitat and biota for identifying potential conflicting forest land uses: montane riparian areas. Forest Ecology and Management 33/34:363-383.

Rinne, J. N. 1991a. An approach to management and conservation of a declining regional native fish fauna: Southwestern United States, pp. 56-60 *In* N. Maruyama et al. (eds)-wildlife conservative: Present trends and perspectives for the 21st Century. Proc. Internatl. Symp. Wildl. Conserv., 5th Internatl. Congr. Zool., Tsukuba and Yokohama, Japan.

Rinne, J. N. 1991b. Habitat use by spikedace, *Meda fulgida* (Pisces: Cyprinidae) in southwestern streams with reference to probable habitat competition by red shiner, *Notropis lutrensis* (Pisces: Cyprinidae). The Southwestern Nat. 36(1): 7-13.

Rinne, J. N. 1992. Physical habitat utilization of fish in a Sonoran Desert stream, Arizona, southwestern United States. Ecol. Freshwater Fishes 1: 1-8.

Rinne, J. N. 1994. Declining southwestern aquatic habitats and fishes: Are they sustainable? Sustainability Symposium. USDA For. Service, Gen. Tech. Rep. RM-247: 256-265.

Rinne, J. N. 1995a. The effects of introduced fishes on native fishes: Arizona, southwestern United States. World Fisheries Conference. April 15-19, 1991, Athens, Greece. Vol 3: 145-158.

Rinne, J. N. 1995b. Stream fishes, pp 1-21. *In*, Tonto National Forest Aquatic and Riparian Ecosystem Workshop. April 18-22, 1995. Arizona Game and Fish Department, Phoenix, Arizona.

Rinne, J. N. In Press a. Sky island aquatic resources: habitats and refugia for native fishes. USDA For. Serv. Gen Tech. Rep. RM-.

Rinne, J. N. In Press b. Native fish replacement in the Southwest: The interactions of hydrology and predation. *In*, Hydrology and Water Resources in Arizona and the Southwest. 17. Ariz. Sect. Amer. Water Resour. Assoc., Hydrol Sect. AZ-NV Acad of Sciences, and The Ariz. Hydrol. Soc. Northern Arizona University, Flagstaff Arizona.

Rinne, J. N. in press c. Southwestern wildfires: Effects on fishes and aquatic macroinvertebrates and management implications. N. Amer. J. Fish. Manage.

Rinne, J. N. and W. L. Minckley. 1985. Patterns of variation and distribution in Apache trout (*Salmo apache*) relative to co-occurrence with introduced salmonids. Copeia 1985: 285-292.

Rinne, J. N. and W. L. Minckley. 1991. Inland native fishes of the Southwest; a declining natural resource. USDA For. Serv. Gen. Tech. Rep. RM-206: 1-45. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Rinne, J. N. and P. R. Turner. 1991. Reclamation and alteration as management techniques, and a review of methodology in stream renovation, pp 219-246. *In*, W.L. Minckley and J. E. Deacon. (eds.), Battle Against Extinction: Native fish management in the American West. Univ. Ariz. Press, Tucson.

Rinne, J. N. and J. Janisch. 1995. Coldwater fish stocking and native fishes in Arizona: Past, present and future, pp 397-406. *In*, J. L. Schramm and R. G. Piper (eds), Use and effects of cultured fishes in aquatic ecosystems. Amer. Fish. Soc. Symposium 15. Bethesda Maryland.

Rinne, J. N. and M. Alexander. in press. Non-native salmonid predation on two threatened native species: Preliminary observations of field and laboratory studies. Proc. Desert Fishes Council 26.

Rinne, J. N., W. L. Minckley, and J. N. Hanson. 1981. Chemical Treatment of Ord Creek, Apache County, Arizona, to re-establish Arizona trout. Arizona-New Mexico Acad. Sci. 16: 74-78.

Rosgen, D. L. 1994. A classification of natural rivers Catena. 22(3): 169-199.

Stefferud J. A. and J. N. Rinne. In Press. Sustainability of fishes in a desert river: The roles of streamflow and introduced fishes. *In*, Hydrology and Water Resources in Arizona and the Southwest 17. AZ Section. Amer. Water Resour. Assoc., Hydrol Sect. AZ-NV Acad of Sciences, and The Ariz. Hydrol. Soc. Northern Arizona University, Flagstaff Arizona.

Sublette, J. E., M. D. Hatch, and M. Sublette. 1990. The fishes of New Mexico. Univ. of New Mexico Press, Albuquerque.

U. S. D. A. 1992a. Ecology-based resource management. Albuquerque, New Mexico

U. S. D. A. 1992b. Woody debris Packet # 1, literature included papers. Nat. Aquatic. Monitoring Center, Utah State Univ.

USDA Forest Service
General Technical Report RM-GTR-272

March 1996

Desired future conditions for Southwestern riparian ecosystems: Bringing interests and concerns together

September 18-22, 1995
Albuquerque, New Mexico

Technical coordinators:

Douglas W. Shaw
USDA Forest Service, Region 3
Albuquerque, New Mexico

Deborah M. Finch
USDA Forest Service
Rocky Mountain Forest and Range Experiment Station
Albuquerque, New Mexico[1]

Sponsors:

New Mexico Riparian Council

Tree New Mexico

New Mexico State Land Office

USDI Fish and Wildlife Service

USDA Natural Resource Conservation Service

USDA Forest Service, Region 3

USDA Forest Service, Rocky Mountain Forest and Range Experiment Station

[1] *Headquarters is in Fort Collins, in cooperation with Colorado State University.*