Regulated Flows, Trout Spawning, and Abundance of Bald Eagles on the Colorado River, Grand Canyon National Park

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Abstract. Rainbow trout (*Oncorhynchus mykiss*) moved into and spawned in Nankoweap Creek, a tributary of the Colorado River in Grand Canyon, during February and March 1990. Abundance of spawning trout in the lower 600 m of the creek peaked at 1,565 fish. Bald eagle (*Haliaeetus leucocephalus*) abundance peaked at 26 during the same period. Movements of spawning trout into Nankoweap Creek were not correlated with river flows between 5,000 and 20,000 cubic feet per second (cfs) but were positively correlated with water temperatures in the creek. The number of trout tagged in the main channel and recaptured in Nankoweap Creek was positively correlated with higher minimum daily flows ($r^2 = 0.41$, $P = 0.003$, df = 17) in the river. Trout were able to enter Nankoweap Creek at all flows observed in the river during the study.

Key words: Bald eagle, migration, predation, rainbow trout, regulated flow, reproduction.

The operation of Glen Canyon Dam since its completion in 1963 has lowered water temperatures and reduced turbidity in the Colorado River, creating ideal conditions for a coldwater trout fishery. Present operations of Glen Canyon Dam are based on the demand for electrical power. Changes in demand create daily vertical stage fluctuations of up to 4 m in the Colorado River. The ability of rainbow trout (*Oncorhynchus mykiss*) to successfully spawn in the river under these conditions has been of major concern to resource managers (Persons et al. 1985; Maddux et al. 1987). Spawning

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continues to be successful in a few tributaries of the Colorado River (Carothers and Minckley 1981; Usher et al. 1984).

Trout were introduced into selected tributaries within Grand Canyon National Park in the 1920's (Maddux et al. 1987). Trout then colonized the mainstream river, both from tributaries where they were already established and from introductions made upstream at Lees Ferry. Trout inhabiting the river eventually found winter conditions in Nankoweap Creek (83.7 km below Lees Ferry) conducive to spawning, and a limited spawn was documented in the creek during the winter of 1977–78 (Carothers and Minckley 1981). The number of spawning trout has increased in the last decade (Maddux et al. 1987).

Bald eagles (*Haliaeetus leucocephalus*) were rare visitors to the river corridor before construction of the dam in the early 1960's and on through the late 1970's (Brown et al. 1989). Small numbers of migrant and wintering eagles began frequenting the river at and near Nankoweap Creek in the early 1980's, apparently in response to the abundant spawning rainbow trout during fall and winter. The numbers of eagles in the vicinity of Nankoweap continued to increase each year. By winter 1988, at least 18 eagles were present at the mouth of the creek, and an unknown number appeared along the river in Marble Canyon upstream of the Little Colorado River (Brown et al. 1989).

Spawning by trout and the resultant eagle concentration at Nankoweap Creek may be influenced by fluctuating flows from Glen Canyon Dam. Casual observations suggest that low Colorado River discharges may inhibit movement by spawning fish into these tributaries (C. O. Minckley, U.S. Fish and Wildlife Service, Parker, Arizona, personal communication). Low water levels during periods of fluctuating flows strand and kill rainbow trout near Lees Ferry (Maddux et al. 1987).

Our objectives were (1) to describe spawning migrations of rainbow trout into Nankoweap Creek, (2) to determine if fluctuating flows from Glen Canyon Dam limit access by trout, (3) to determine the length of stay of rainbow trout in Nankoweap Creek, and (4) to relate abundance of bald eagles in the vicinity of Nankoweap Creek to abundance of trout in the creek.

Study Area

Nankoweap Creek is a small, perennial, tributary stream to the Colorado River in Grand Canyon National Park. Its drainage basin encompasses 84.4 km^2 on and below the Kaibab Plateau (Webb et al. 1987). The creek flows 14 km from approximately 2,900 m elevation to confluence with the river at an elevation of approximately 880 m. The creek enters the Colorado River at river kilometer 83.7, 110 km downstream from Glen Canyon Dam (Stevens 1983).

Nankoweap Creek is fed by perennial springs as well as runoff and snowmelt from the Kaibab Plateau. Annual flows range from 0 to about 35 cubic feet per second (cfs), but winter flows normally range from 1 to 6 cfs (Johnson and Sanderson 1968). The lower 3.2 km are composed of shallow riffle or run habitats interspersed with pools along a narrow channel and a typical winter flow of 1 cfs.

Nankoweap Creek enters the Colorado River through a broad delta (2 km across) that constitutes the widest portion of the Marble Canyon region of Grand Canyon above the Little Colorado River. The lower 500 m meanders across the flat Nankoweap delta.

Methods

Physicochemical Analyses

Nankoweap Creek was divided into three 200-m reaches beginning at the mouth and extending 600 m upstream (reach 1, 0–200 m; reach 2, 200–400 m; reach 3, 400–600 m). Stream morphology was described by channel depth, pool size, and percent substrate in each reach. Substrate was analyzed by visually assessing random points generated from a random numbers table. Substrate categories included silt, sand, gravel, cobble, boulder, and vegetation. Substrate was additionally classified as armored where the stream bottom was highly compacted and cemented.

A Hydrolab Datasonde DS2H (Series 2270) was installed in Nankoweap Creek to record water temperature, dissolved oxygen, pH, and conductivity continuously over the study period. In addition, a Yellow Springs Instruments dissolved oxygen and temperature meter (Model 51B) was used to record data during each fish sampling period. Discharge was measured periodically throughout the study in the lower 100 m of the creek. A Marsh–McBirney current meter mounted on a standard wading rod was used to measure stream velocity. Stream width and depth were taken at each cross-section. Cross-sections to determine discharge were replicated at each sample site.

Trout Abundance and Spawning Phenology in Nankoweap Creek

Trout in Nankoweap Creek were counted by visual observations at least 3 nights/week and at low, moderate, and high river flows (specific discharges were not measured). Night counts were made to minimize effects on bald eagle behavior, and because fish were less excitable after dark and easier to count. Trout abundance was recorded for each study reach and combined for a total count. Fish counts when abundance was low were considered accurate in the runs, riffles, and pools. When numbers increased, trout densities in pools were estimated by averaging three to four counts by each of several workers.

Samples approximating 50 fish each were collected by dip net from each reach on nights when counts were conducted. All fish collected were measured for standard length (SL) and total length (TL) in millimeters, tagged with color- and number-coded Floy dart tags, classified according to sex and reproductive condition, and released. The proportion of spawning to nonspawning fish was used to indicate height of spawning activity and changes in spawning activity over the study period.

Trout Movement

At the beginning of the study, rainbow trout were obtained from the river by angling. These trout were marked with individually numbered Floy tags, measured, and their reproductive condition visually determined. During this capture effort the stream mouth was blocked to assure that the marked fish were added only to the river population.

Movement of trout (fish/h) into Nankoweap Creek was quantified by counting at the mouth on 3 to 4 nights/week. Additional daytime counts were made by using a spotting scope from an observation post. The shallow water at the mouth of Nankoweap Creek afforded clear visibility for counting. We also recorded the number of fish tagged in the river that were recaptured in Nankoweap Creek. Data on movements were compared with data on river discharges to determine if flows influenced the movement of trout into the stream.

Movement into Nankoweap Creek began on 16 February and peaked on 2 March 1991. Correlations of trout movements with temperature and river discharge are based within this period.

Duration of Trout Residence

Duration of residence in Nankoweap Creek was determined for each marked fish as the number of days between their day of initial capture and marking and the day of last recapture in the creek; the days of marking and last recapture were counted as full days of residence. The duration of residence within each reach was also determined for each marked fish in a similar manner.

Bald Eagle Observations

An observation point was established approximately 700 m from the mouth of Nankoweap Creek (Brown and Leibfried 1990). The location provided an unobstructed view of the stream mouth and of the main river, both upstream and downstream.

All eagles entering the study area were counted, and notes were made concerning age and identifying plumage patterns (Southern 1964, 1967; Bortolotti 1984; Clark 1987; Brown and Leibfried 1990). The minimum number of eagles in the study area per day was determined by counting the maximum number of individuals that could be identified by age class and plumage patterns.

Results

Physicochemical Analysis

Water temperature in Nankoweap Creek was variable and ranged from –0.3 to 17.9°C during the study. Daily ranges frequently exceeded 10°C during February and March—typical of low volume, shallow streams (Hynes 1970). Stream temperatures in early February were below preferred temperatures (10–12°C) for spawning rainbow trout (Scott and Crossman 1973) but were within the preferred range by the end of the month.

Dissolved oxygen varied with the ability of cooler water to hold oxygen (Wetzel 1975). Although dissolved oxygen concentrations varied widely, they never dropped below levels necessary (Carlander 1969) for trout survival. Conductivity and pH were moderate and relatively stable during the time that the equipment was operating. These parameters were recorded during the first half of the field effort due to equipment failure.

Discharge from Nankoweap Creek averaged 0.86 cfs (n = 13, range = 0.54–1.14 cfs). The variability in estimated discharges was due to subsurface flow within the stream gravels (Dunne and Leopold 1978) and heterogeneity of the stream channel. No spates were observed during the study.

Acceptable spawning substrata for trout occurred in each reach. Stream substrate was dominated by gravels in all three study reaches (Table). The percent of substrates comprising gravel was highest in reach 1 and decreased upstream. Silt, sand, and percent armoring (33) were highest in reach 3.

During periods of low (<~5,000 cfs) Colorado River discharge, Nankoweap Creek flowed from a single channel 1.6 m wide into a series of small braided channels in the lower 20 m of the stream. Average channel depth ranged from 4.0 to 6.3 cm. The substrate was predominantly gravel (65%) with some cobble (20%), which allowed subsurface flow to further reduce surface flow. Shallow water, increased subsurface flow, and steep

Table. Substrate composition, as percent of total, for the three study reaches of Nankoweap Creek in Grand Canyon, February and March 1990.

	Reach		
Substrate	1	2	3
Silt	1.25	1.14	4.75
Sand	9.01	16.3	18.25
Gravel	58.13	41.82	24.25
Cobble	18.44	18.18	10.25
Boulder	15.00	21.82	13.25
Armored	0.00	0.00	32.50
Vegetation	trace	0.91	trace
Sample size	16	22	20

gradient contributed to the impediments facing spawning trout in their attempts to move into Nankoweap Creek.

Trout Abundance and Spawning Phenology

Rainbow trout began moving into Nankoweap Creek about 12 February, but this pulse of early movement was interrupted by a decline in water temperature of 7°C over a 2-day period (Fig. 1). The immigration resumed on 20 February. Trout numbers increased steadily to a peak on 2 March with 1,565 fish in the lower 600 m of the stream. From 25 February through 5 March, the number of trout in Nankoweap Creek exceeded 1,000. Trout abundance declined steadily after the peak.

All adult trout observed during the 6-week study ranged from 204 to 493 mm SL and were in spawning or postspawning condition. During February, from 94.6 to 97.7% of all trout were in spawning condition. Postspawning or spent fish increased from 5.4 to 15.2% of adult trout after peak abundance in early March.

The first spawning mortalities were observed in the week following peak trout abundance. Numbers of dead trout along the stream bank increased from 20 to more than 100 by 12 March, and moribund fish were observed beached in shallow areas. In addition to dead and dying trout, the number of trout with worn caudal, anal, and ventral regions increased, indicating postspawning condition.

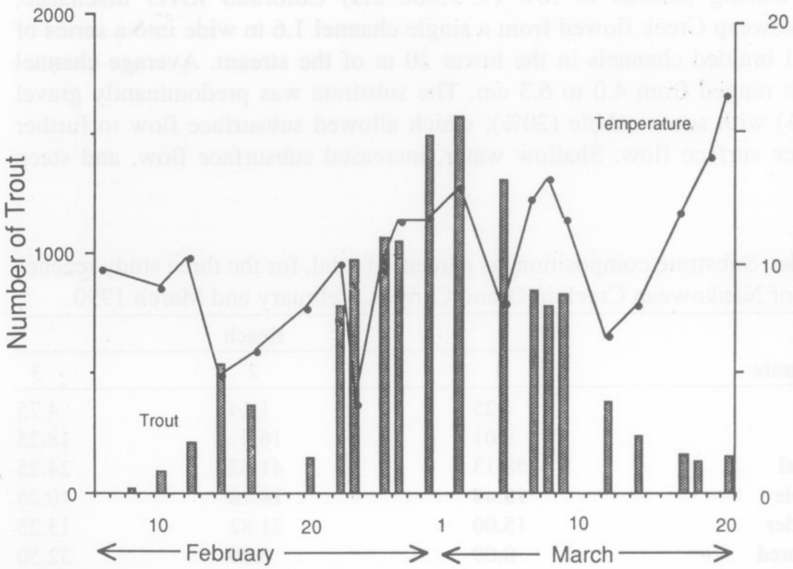

Fig. 1. Water temperatures and numbers of rainbow trout in Nankoweap Creek, Grand Canyon, February–March 1990.

Fry, first observed in Nankoweap Creek on 8 March, provided evidence of successful spawning. Fry collected on 8 March averaged 22 mm TL ($n = 3$, range = 18–25 mm, SD = 3.6). By about 20 March, average fry length had increased to 27 mm ($n = 8$, range = 24–33 mm, SD = 3.1). Incubation time for rainbow trout in Nankoweap Creek was 4–7 weeks.

Trout Movement

Rates of movement of trout (fish/h) into Nankoweap Creek did not correlate with observed river flows ($y = 3.958 - 0.0015x$, $r^2 = <0.01$, $n = 30$). Nighttime movements into the creek were greater than daytime movements (Fig. 2).

The Nankoweap spawning run may be triggered when stream temperatures warm to a critical threshold. Temperatures above 5–7°C corresponded to the largest influx and in-stream abundance of trout (Figs. 1 and 2). Furthermore, during 14–20 February, trout abundance dropped from 500 to near 100 fish after a sharp decline in stream temperature due to a winter storm (Fig. 1). Daily water temperature during this period ranged from ~0°C to ~8°C. An increase in air and creek temperatures was followed by an increase in numbers of trout moving into the stream (Figs. 1 and 2).

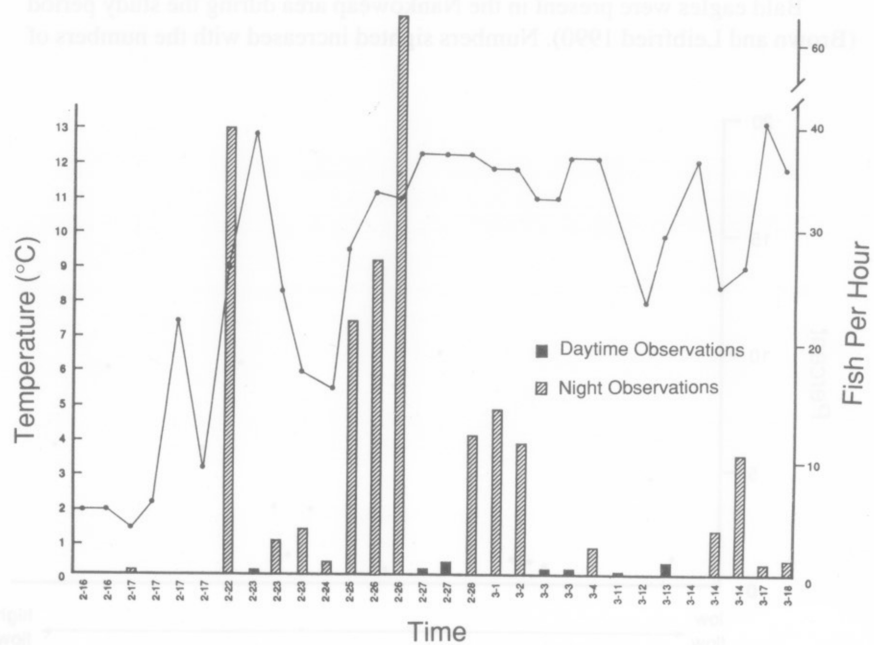

Fig. 2. Numbers of rainbow trout entering Nankoweap Creek from the Colorado River during day and night at various creek temperatures in Nankoweap Creek, Grand Canyon, February–March 1990.

Trout attempted to move into the stream in pulses. Although there were times, even during high river flows, when fish were not moving into the stream, there were also times when trout moved across 15–20 m of gravel covered by less than 5 cm of water. There was no indication that trout were prohibited from entering Nankoweap Creek at any observed flows (from approximately 5,000 to 20,000 cfs).

Numbers of trout tagged in the Colorado River and recaptured in Nankoweap Creek were significantly correlated with discharges from Glen Canyon Dam (Fig. 3; $r^2 = 0.41$, $P = 0.003$, DF = 17, $n = 19$). The data (Fig. 3) are expressed as a percentage of tagged fish recaptured to account for additional tagged fish released into the river during the study. A greater number of river-tagged fish were recaptured in Nankoweap Creek at intermediate and high flows than at low flows.

Residence in Nankoweap Creek

On average, trout remained for 6 days in Nankoweap Creek (range = 1–34 days, $n = 507$). Trout spent an average of 2.4 days in reach 1 (range = 1–26 days), 2.3 days in reach 2 (1–25 days), and 1.3 days in reach 3 (1–25 days).

Numbers of Bald Eagles

Bald eagles were present in the Nankoweap area during the study period (Brown and Leibfried 1990). Numbers sighted increased with the numbers of

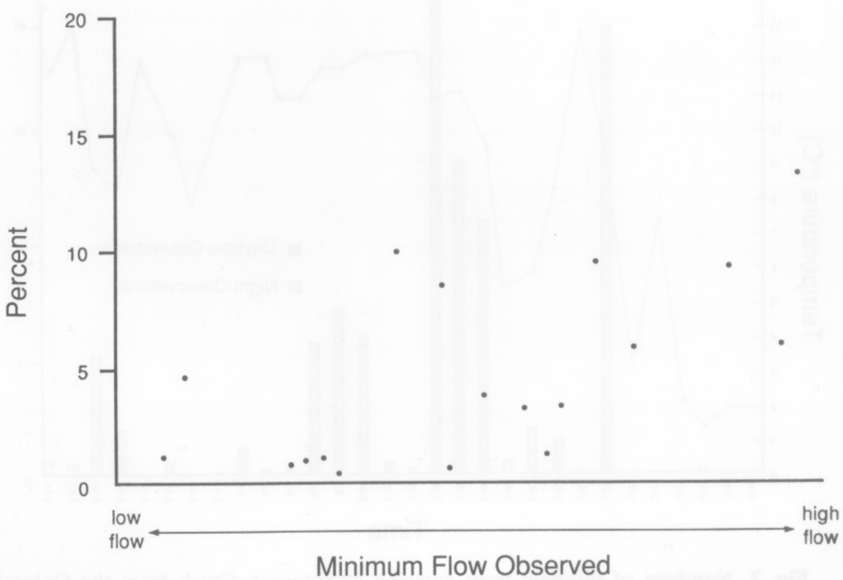

Fig. 3. Percentage of rainbow trout, tagged in the Colorado River and recaptured in Nankoweap Creek, relative to minimum flows observed on the day of recapture, Grand Canyon, February–March 1990.

rainbow trout in Nankoweap Creek (Fig. 4). Bald eagle numbers were highest during the peak of trout abundance—23 February through 5 March—and decreased with declines in trout abundance.

Discussion

Spawning rainbow trout are influenced by a complex of factors that control spawning movements and behavior (Scott and Crossman 1973). Rainbow trout spawn in tributaries of larger rivers or lakes. Temperature of the tributary is often the primary cue that initiates spawning migrations (Scott and Crossman 1973; Sigler and Sigler 1987). Naiman et al. (1987) suggested that salmonids move into side streams when mainstem temperatures equal tributary temperatures.

In Nankoweap Creek, this latter pattern was observed during February 1990 when trout abundance increased dramatically as stream temperatures warmed to the same temperature as the mainstem. Fish per hour moving into Nankoweap Creek and increasing water temperatures were positively correlated ($r = 0.64$). During January 1989, water temperatures in Nankoweap Creek never rose above 1˚C, and trout abundance never exceeded 10 fish for the week (Brown et al. 1989).

Trout numbers in Nankoweap Creek increased with stream temperature during the month of February until the peak of abundance. At this time, stream temperatures continued to rise as spawning activity waned. As stream temperatures approached 16–17˚C— above preferred spawning temperatures of 10–12˚C (Scott and Crossman 1973)—abundance of trout declined. We do not know if the decline was related to temperature or to a natural decline in spawning activity. Increased spawning deaths observed after the peak of

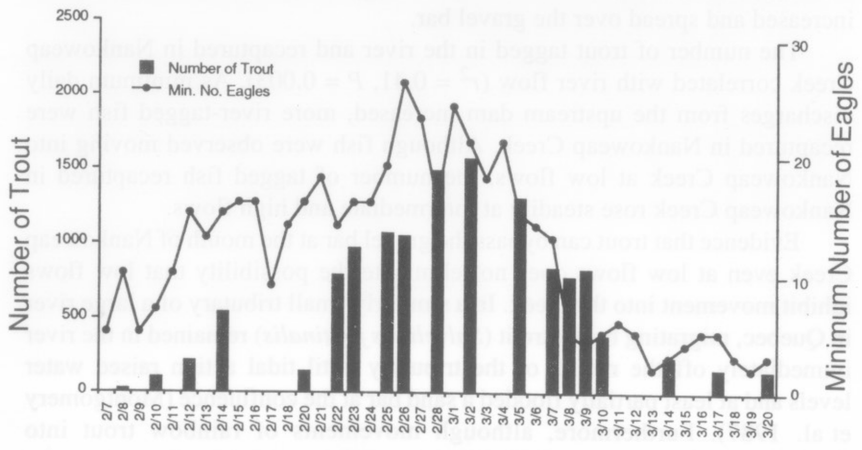

Fig. 4. Minimum number of bald eagles sighted per day at and near Nankoweap Creek and number of rainbow trout per day in Nankoweap Creek, a tributary to the Colorado River, Grand Canyon, February–March 1990.

abundance may indicate that the spawn was waning and temperature was not responsible for the decline in trout numbers.

Local weather patterns may control tributary temperatures in the Grand Canyon, especially in Nankoweap Creek. Streams of low discharge that flow through open valleys have highly variable water temperatures that fluctuate with ambient air temperatures (Hynes 1970; Usher et al. 1984). These streams show a positive correlation between ambient air temperatures and increasing distances from their sources. Usher et al. (1984) demonstrate that temperatures of both North Rim and South Rim tributaries become extremely variable as distance from their source springs increases. Given the influence of water temperature on initiation of spawning migrations, we expect that the onset and structure of spawning migrations will vary among years and may not correlate well with timing of eagle migrations.

Observations of spawning aggregations in Nankoweap Creek from 1984 to 1990 showed that trout can spawn any time from September through March (Maddux et al. 1987). Although spawning aggregations, egg deposition, and fry emergence are documented for Nankoweap Creek (Maddux et al. 1987; Kondolf et al. 1989), successful recruitment into the mainstem fish population has not been documented.

Sporadic and intermittent spawning movements confounded the ability to directly relate movements to river stage. During some observation periods, for example, trout moved into Nankoweap Creek seemingly without regard to river levels. At other times and under similar discharges, no fish were observed attempting to enter the creek.

Numbers of fish moving into Nankoweap Creek varied from 0 to 62 fish/h during the study period. Trout were not prohibited access to Nankoweap Creek under any flow regimes observed during our study. Fish moved freely into the creek even while low river flows exposed a large gravel bar at the mouth. Trout seemed, however, to have easier access to the creek as flows increased and spread over the gravel bar.

The number of trout tagged in the river and recaptured in Nankoweap Creek correlated with river flow ($r^2 = 0.41$, $P = 0.003$). As minimum daily discharges from the upstream dam increased, more river-tagged fish were recaptured in Nankoweap Creek. Although fish were observed moving into Nankoweap Creek at low flows, the number of tagged fish recaptured in Nankoweap Creek rose steadily at intermediate and high flows.

Evidence that trout can bypass the gravel bar at the mouth of Nankoweap Creek even at low flows does not eliminate the possibility that low flows inhibit movement into the creek. In a similarly small tributary of a large river in Quebec, migrating brook trout (*Salvelinus fontinalis*) remained in the river immediately off the mouth of the tributary until tidal action raised water levels and at least partially flooded a sand bar at the confluence (Montgomery et al. 1987). Furthermore, although movements of rainbow trout into Nankoweap Creek during 1990 did not correlate with river flows between ~5,000 cfs and 20,000 cfs, lack of flows at the extreme low range of possible releases from Glen Canyon Dam prohibited analysis of effects at discharges ≤5,000 cfs.

The trout presence below Glen Canyon Dam seems to have promoted increases in numbers of wintering and migrating bald eagles in the Grand Canyon. Numbers of eagles correlated positively with the availability of trout during 1990 (Brown and Leibfried 1990). A less intense survey in 1989 (Brown et al. 1989) found few bald eagles in the Nankoweap area, and the number of rainbow trout in Nankoweap Creek never exceeded 10. Cold stream temperatures (<5°C) were the likely reason that so few trout entered Nankoweap Creek during 1989. Variation in numbers of trout and of eagles between years suggests a strong influence of unpredictable environmental conditions on the timing of appearance and of the relative abundance of these interacting species.

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