The Condor 100:745–748
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INFLUENCES OF FLUCTUATING RIVER FLOWS ON BALD EAGLE FORAGING BEHAVIOR[1]

BRYAN T. BROWN
SWCA, Inc., Environmental Consultants, 56 West 400 South, Suite 201, Salt Lake City, UT 84101-2108

LAWRENCE E. STEVENS
Grand Canyon Monitoring and Research Center, P.O. Box 22459, Flagstaff, AZ 86002-2459

TERESA A. YATES
P.O. Box 2326, Flagstaff, AZ 86003-2326

Abstract. We examined habitat use, prey capture, and foraging success of Bald Eagles (*Haliaeetus leucocephalus*) in winters of 1990 and 1991 to evaluate influences of hourly fluctuating river flows from Glen Canyon Dam along the Colorado River in Grand Canyon National Park, Arizona. Patterns of habitat use were strongly dependent upon fluctuating flows in both years. Foraging in river, shore, and isolated pool habitats decreased to 0% at flows > 568 m^3 sec^{-1}, whereas foraging in adjacent creek habitat increased to 100%. More foraging attempts occurred farther from the river in adjacent creek habitat as river flows increased, but this did not influence foraging success in creek habitat. Rainbow trout (*Oncorhynchus mykiss*) stranded by fluctuating river flows comprised 12% and 19% of eagle prey captures in 1990 and 1991, respectively. Foraging success in river habitat decreased in 1990 as river flows increased from < 284 m^3 sec^{-1} (74%) to > 284 m^3 sec^{-1} (39%); foraging success in river habitat was independent of fluctuating flows in 1991. Low river flows exerted neutral or positive influences on eagle habitat use and prey capture, whereas high river flows reduced eagle foraging habitat diversity, lowered foraging success in river habitat, and restricted foraging opportunities. Management strategies to limit high river flows and sustained flooding during peak eagle concentration may benefit wintering eagles.

Key words: Bald Eagle, Colorado River, fluctuating river flows, foraging behavior, habitat use, Haliaeetus leucocephalus, *human impact.*

Changing environmental conditions affect foraging behavior and success of Bald Eagles *Haliaeetus leucocephalus* (Knight and Skagen 1988). Foraging rates and strategies of Bald Eagles at the Columbia River estuary are strongly influenced by tidal cycles, with foraging and scavenging most common at low tide (Watson et al. 1991). Hourly fluctuating river flows below hydroelectric dams mimic tidal cycles and may have similar influences on eagle foraging behavior. Information on the effects of fluctuating river flows on Bald Eagle foraging behavior is either anecdotal (Stalmaster 1987), pertains to the maintenance of ice-free waters by hydroelectric operations (Stalmaster and Plettner 1992), or correlates prey vulnerability with changing river flows (Hunt et al. 1992). Although fluctuating river flows below dams influence thousands of kilometers of Bald Eagle foraging habitat, detailed information on fluctuating flow impacts on winter eagle foraging behavior is lacking.

We examined influences of hourly fluctuating river flows from Glen Canyon Dam on foraging behavior and success of wintering Bald Eagles along the Colorado River in Grand Canyon National Park, Arizona. Our objectives were to determine if fluctuating river flows influenced eagle habitat use, foraging success, and prey capture.

METHODS

We observed eagle foraging along 4.8 km of the Colorado River at and near the confluence of Nankoweap Creek (elevation 850 m), as described previously (Brown 1993). Up to 26 migrating or wintering eagles day^{-1} were detected foraging in the study area (Brown and Stevens 1992). Numbers of eagles day^{-1} were estimated by adding maximum numbers of concurrently-visible individuals of each age class present (age classes after Bortolotti 1984), a conservative technique which likely underestimated eagle abundance. Eagles

[1] Received 2 March 1998. Accepted 17 July 1998.

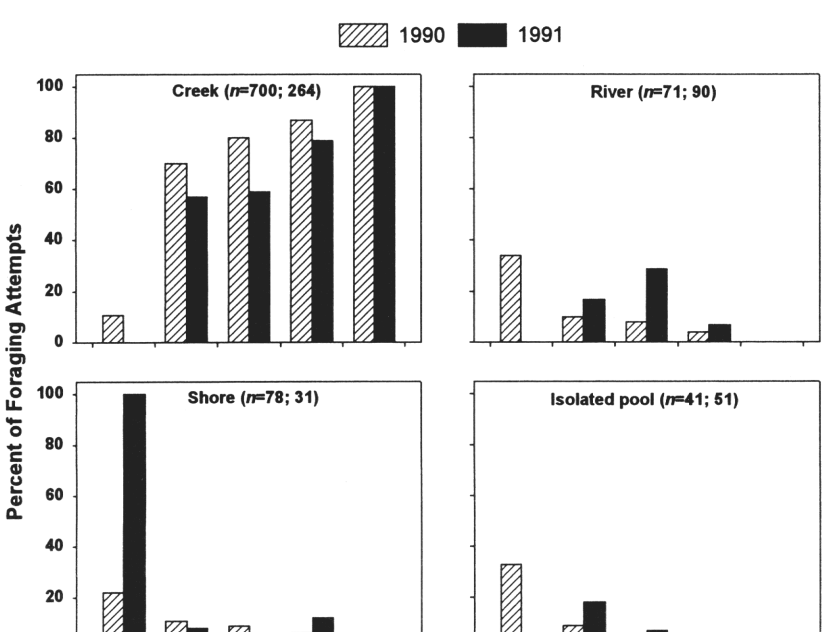

FIGURE 1. Percent of Bald Eagle foraging attempts by habitat and river flow interval along the Colorado River in Grand Canyon National Park, Arizona, 1990 (n = 890) and 1991 (n = 436). Sample sizes by habitat are indicated for 1990 and 1991, respectively.

were not banded or marked, and we were unable to differentiate between most individuals of similar age; therefore, we were unable to determine the number of foraging attempts per individual. The extent of pseudoreplication was estimated to be low due to the highly transient nature of wintering eagles in Arizona (Grubb et al. 1989) and the high daily variance in eagle abundance at our study site (Brown and Stevens 1992). We estimated that approximately 75–100 individual eagles used our study area each study period.

Eagles concentrated in the study area due to aquatic habitat changes brought about by the operation of Glen Canyon Dam, 109 km upstream, and the recent introduction and proliferation of rainbow trout *Oncorhynchus mykiss* (Brown et al. 1989). Trout presence was maintained both by artificial stocking and natural reproduction (Angradi 1994); Nankoweap Creek is the only tributary to the Colorado River in the first 165 km below Glen Canyon Dam that supports a sizeable winter trout spawn (Brown et al. 1989). Healthy rainbow trout, captured alive, were the principal prey of eagles in the study area (Brown 1993).

We identified four eagle foraging habitats in the study area: creek (0.6 km), river (4.8 km), shore (10.8 km, with 1.2 km adjacent to creek habitat and 9.6 km adjacent to river habitat), and isolated pools (≤ 50 small ephemeral basins at shoreline that existed at low river flows).

Vertical river level fluctuations of 2–3 m occurred daily as a result of water released for hydroelectric power generation at Glen Canyon Dam. Colorado River flows ranged from 110–680 m^3 sec^{-1} during the 1990 study period ($\bar{x} \pm$ SD = 331 ± 116) and 116–615 m^3 sec^{-1} in 1991 (289 ± 113). River flow fluctuations resulted from kinematic wave translation, with peak flows reaching our study area about 18 hr after release from the dam (Wiele and Smith 1996). This resulted in river flows that were typically highest in early morning. River flows are best described as a function of flow rates (m^3 sec^{-1}) rather than vertical gauge measurements because hydroelectric dams manage water releases based on volume per unit time, and because vertical gauge measurements differ by locale within a river depending upon channel geomorphology (Schmidt and Graf 1990).

We recorded foraging events using up to five observers from 30 min before sunrise to 30 min after sunset, January–March, 1990–1991. For each foraging attempt we recorded: date, time, habitat, distance upstream (if creek habitat), and success of attempt. Distance upstream for foraging events in creek habitat was categorized as close (< 50 m from river) or far (> 50 m from river). We obtained river flow data from the U.S. Geological Survey gauging station upstream from the Little Colorado River confluence near Desert View, Arizona, 15 km downstream of our study area (2 hr by river). We estimated river flows for foraging attempts by lagging the time of each foraging attempt by 2 hr and then using corresponding river flow data from the gauging station. We established three river

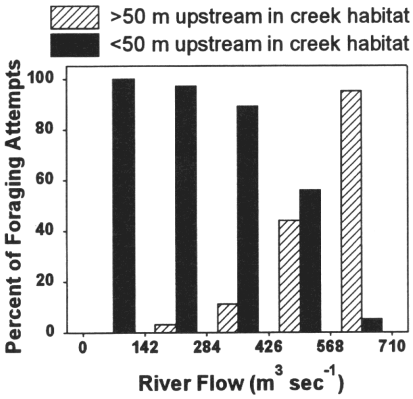

FIGURE 2. Percent of Bald Eagle foraging attempts in creek habitat in 1990 (n = 700) by distance from the Colorado River and river flow interval, Grand Canyon National Park, Arizona.

flow categories: low (< 284 m^3 sec^{-1}), intermediate (284–568 m^3 sec^{-1}), and high (> 568 m^3 sec^{-1}). We did not analyze distribution of foraging attempts in creek habitat in 1991 because drought reduced creek flows and limited trout access. Prey obtained from isolated pool and shore habitats adjacent to the river were stranded and made available by fluctuating river flows.

We analyzed probabilities that foraging attempts in creek habitat far from the river differed by river flow using a logistic regression model produced from untransformed data with river flow as the independent variable and foraging success as the dependent variable (SYSTAT Version 4, Wilkinson 1989). We performed all other analyses using χ^2-tests for association with Yates' correction. Significant difference was accepted at $P < 0.05$. Sample sizes of some analyses differed due to missing data.

RESULTS

Most eagle foraging occurred in creek habitat at river flows > 142 m^3 sec^{-1} in both 1990 and 1991 (Fig. 1). Foraging in creek habitat increased as river flows increased in both 1990 ($\chi^2_6 = 37.8$, $P < 0.001$) and 1991 ($\chi^2_6 = 32.0$, $P < 0.001$); foraging in river, shore, and isolated pool habitats decreased with increasing river flows. No foraging occurred in river habitat at river flows > 504 m^3 sec^{-1}, and all foraging occurred in creek habitat at river flows > 568 m^3 sec^{-1}.

Foraging success in river habitat in 1990 decreased from 74.0% (20 of 27) at low river flows to 38.6% (17 of 44) at intermediate and high river flows combined ($\chi^2_1 = 9.3$, $P = 0.002$). Foraging success in river habitat in 1991 was similar for low (16 of 34, 47.0%) vs. intermediate and high river flows combined (14 of 39, 28.6%; $\chi^2_1 = 3.0$, $P = 0.08$).

Distribution of foraging attempts in creek habitat far from the river compared to foraging attempts in creek habitat close to the river differed by river flows in 1990 (Fig. 2). Increasing river flows corresponded to more foraging attempts in creek habitat far from the river ($Z = 11.31$, $P < 0.001$). Foraging success in creek habitat far from the river (102 of 130, 78.5%) was similar to that close to the river (412 of 549, 75.0%; $\chi^2_1 = 0.74$, $P = 0.39$).

TABLE 1. Bald Eagle prey captures (n[%][a]) by foraging habitat along the Colorado River in Grand Canyon National Park, Arizona, January to March, 1990 and 1991. Shore habitats were classified as adjacent to either creek or river habitats.

Year	Creek	River	Shore: creek	Shore: river	Isolated pool	Totals
1990	534 (78)	37 (5)	36 (5)	42 (7)	37 (5)	686
1991	187 (65)	30 (10)	18 (6)	13 (5)	41 (14)	289
Totals	721 (73)	67 (7)	54 (6)	55 (6)	78 (8)	975

[a] Percentages refer to percent of row totals.

Prey obtained from shore habitat adjacent to the river and in isolated pool habitats (i.e., prey provided by fluctuating river flows) comprised 14% of total prey captures in both years combined. A greater proportion of prey captures resulted from daily fluctuating river flows in 1991 compared to 1990 (Table 1; $\chi^2_1 = 13.8$, $P < 0.001$).

DISCUSSION

We found that fluctuating river flows influenced habitat use, prey capture, and foraging success of Bald Eagles. Low river flows resulted in eagles capturing and scavenging proportionally more prey from isolated pools and shore habitat adjacent to the river, particularly in 1991. These habitats were inundated at higher river flows, reducing or eliminating prey availability. This is analogous to the finding of Watson et al. (1991) that eagles scavenged carrion most often at low tide in the Columbia River estuary. Higher river flows inundated creek habitat close to the river and resulted in a shift to increased use of creek habitat far from the river with no corresponding change in foraging success.

Intermediate and high river flows resulted in a shift to greater use of creek habitat during both years. Because foraging success was greater in creek habitat (Brown 1993), this shift may have had a positive influence on prey capture for eagles that had the opportunity to alternately forage in creek habitat. Lower foraging success in river habitat at higher river flows may have been partly responsible for this shift in habitat use in 1990.

Increased use of creek over river habitat at intermediate and high river flows may have occurred because of shallow water in creek habitat and the decreasing availability of fish in river habitat with increasing river depth (Watson et al. 1991). Alternatively, use of creek habitat may have increased at intermediate and high river flows because of its relative stability compared to the relative instability of river, shore, and isolated pool habitats. Foraging conditions in creek habitat were independent of river flows and changed little during observation periods. In contrast, foraging conditions in river, shore, and isolated pool habitats were highly variable depending upon river flows. We conclude that wintering eagles along the Colorado River modified their

foraging behavior in response to dynamic changes in prey availability. Eagles opportunistically foraged in habitats with greater prey accessibility and in which they had a higher probability of success. Eagles foraging in river habitat at localities where adjacent creek habitat is not available as an alternative may experience a reduction in prey availability or foraging success at intermediate to high river flows. Higher river flows increase water depth, turbidity, and velocity which likely increase foraging difficulty. Knight and Skagen (1988) demonstrated that high river flows in the Nooksack River, Washington, decreased prey availability for Bald Eagles and caused a corresponding shift in eagle foraging behavior.

Long-term maintenance of prey populations is the key management consideration for wintering Bald Eagles (Stalmaster 1983), yet the influence of fluctuating river flows on prey populations is poorly understood (Angradi 1994). As an alternative, short-term management to benefit eagle foraging success, prey capture and habitat use also could be considered. Although river flow management criteria to benefit eagles will vary between river systems, our findings may apply to many dam-controlled rivers that are ice-free in winter. Eagles foraging in geologically constrained rivers may experience reduced foraging habitat diversity, lower foraging success, and reduced prey availability with increasing river flows. River management strategies that minimize high river flows and sustained flooding during peak eagle concentrations (late February in our study area; Brown and Stevens 1992) may benefit wintering eagles by increasing foraging success.

Funding was provided by U.S. Bureau of Reclamation Glen Canyon Environmental Studies (GCES), and we thank D. Wegner and the GCES staff. E. Baldwin, P. Becker, D. Bills, M. Buzan, B. Casler, L. Daly, B. Dye, L. Hall, C. Hallett, C. Karas, A. Kelso, N. Kline, R. Mesta, M. Murov, N. Nahstoll, M. Sogge, and A. Zwinger assisted with field observations. J. Korn (GCES) compiled river flow data from U.S. Geological Survey files. Logistical support was supplied by O.A.R.S., Inc., of Flagstaff, Arizona. M. Trosset provided statistical advice. Administrative liaison was provided by the National Park Service. W. G. Hunt suggested improvements to study design. H. Gross prepared illustrations. R. G. Anthony, T. G. Grubb, J. M. Jenkins, S. C. Jones, W. D. Koenig, J. M. Meyers, M. R. Ryan, and two anonymous reviewers commented on early drafts of this manuscript.

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