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Doing Zooarchaeology as if It Mattered: Use of Faunal Data to Address Current Issues in Fish Conservation Biology in Owens Valley, California

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Ecologists are increasingly incorporating concepts such as "legacy" into their explanations of current ecosystems (Harding et al. 1998). This approach acknowledges that understanding the structure and function of extant ecosystems (or predicting future responses to climate change) requires knowledge of historical forces that have been operating for decades, centuries, or longer (Foster 2000; Moorhead et al. 1999). Indeed, recognition of the need for such long-term historical records is demonstrated by the level of National Science Foundation funding for the Long-Term Ecological Research (LTER) network (Kaiser 2001b; LTER Network 2001). Over 1,100 researchers funded by the LTER carry out research on 24 designated sites that have been studied from a few years to several decades (Kaiser 2001b). These studies cover a range of topics with the overall goal of "investigating ecological processes over long temporal and broad spatial scales" (LTER Network 2001). This goal is precisely that of zooarchaeology. Yet, to our knowledge, zooarchaeological expertise and data have not been incorporated into the LTER network. Our point is simply that ecological sciences seeking to understand the long-term properties of ecosystems have direct access to such information through zooarchaeology.

Zooarchaeology needs to collaborate with wildlife sciences because of the increasing speed with which habitats and biotas are being lost in the face of human population growth and habitat destruction (Minckley and Deacon 1991; Vitousek et al. 1997). In response to legislation such as the

Endangered Species Act of 1973 (16USC1531–1547, Public Law 93–205), recovery plans are constantly being developed across the United States. Drawing from recent, often limited historical records, decisions are routinely made on which taxa are native, which are exotic, which should be targeted for recovery, and which should be disregarded. In stark terms, these are determinations of which organisms "belong on the ark." Given zooarchaeology's (and paleontology's) access to faunal records dating back hundreds and thousands of years, we can assist with these decisions. To demonstrate this with respect to fisheries management, we here discuss our recent work on the ancient fish fauna of Owens Valley, California.

BACKGROUND

Owens Valley is a deep, 130-km-long block-faulted graben in southeastern California, on the western edge of the hydrographic Great Basin (Figure 2.1). It is a narrow, roughly north–south-trending valley sandwiched between two mountain ranges with 14,000-ft (4,265-m) peaks. The Sierra Nevada Range to the west captures most of the precipitation arriving from the west; the Inyo-White Mountains lie to the east. Whereas only 16 cm of rain fall on the valley floor, a significant winter snowpack in the high Sierra provides meltwater throughout the year. Owens River heads in the Sierra Nevada north of Owens Valley and is fed by numerous tributaries draining the range at various points along the valley. Prior to historic water-diversion projects, the river traveled southward about 130 km before it emptied into Owens Lake. Historically the lake was shallow (2–15 m), was moderately saline (5–15 percent salts [Smith and Bischoff 1997]), and did not support fish populations (Gilbert 1893). The Quaternary record of Owens Lake shows that it has undergone significant changes in water level and chemistry over the last several hundred thousand years (Benson et al. 1996; Benson et al. 1997; Smith and Bischoff 1997). Basically, the lake is a remnant of a vast Pleistocene lake system that once connected basins extending from south of Mono Lake on the north to Death Valley at the southern end of the chain (Hubbs and Miller 1948; Miller 1946; Sada and Vinyard 2002).

Although minor changes to the historic aquatic system began as early as the 1870s, when irrigation projects began to divert Owens River water, the aquatic system was drastically altered beginning in 1913 with the construction of the Los Angeles Aqueduct. Reservoirs were constructed, canals were dug, and most significant, much of the water from Sierran streams and the Owens River itself was siphoned off, seriously reducing the amount

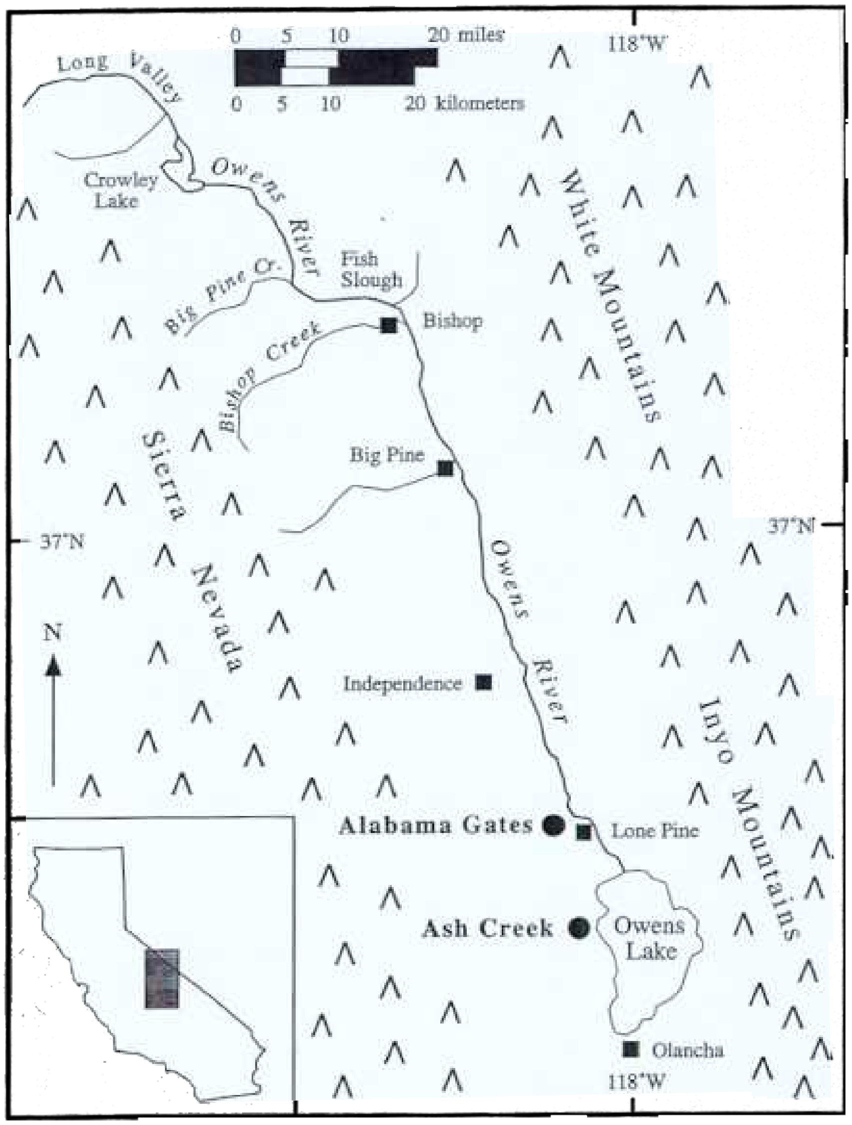

Figure 2.1. Owens Valley, California, showing locations of geographic features and archaeological projects. Circles denote archaeological projects; squares denote towns.

of water that reached the valley bottom (Kahrl 1982). By the 1930s Owens Lake had become a dry playa that accumulates water only in exceptionally wet years. Sometime before 1890 catfish (Ictaluridae), carp *(Cyprinus carpio)*, and salmonids were introduced to the basin (Gilbert 1893), and not long after, bass (*Micropterus* sp.), sunfish (*Lepomis* sp.), and other alien fish and amphibians were introduced (U.S. Department of the Interior, Fish and Wildlife Service 1998).

Given the major loss of habitat and the introduction of alien, non-native species, the populations of most native fish in the valley have been in severe decline for the last 75 years. Of the four native species, two are endangered (Owens pupfish *[Cyprinidon radiosus]* and Owens tui chub *[Gila bicolor snyderi]*), and one is a "species of concern" (Owens speckled dace [*Rhinichthys osculus* ssp.]); only one species (Owens sucker *[Catostomus fumeiventris]*) is believed to be doing relatively well (U.S. Department of the Interior, Fish and Wildlife Service 1998). Owens Valley fish show a high level of endemism typical of Great Basin fish in hydrologically isolated basins; two unique species are present (the sucker and pupfish), and two unique subspecies (the chub and dace) occur in the valley (Miller 1973; U.S. Department of the Interior, Fish and Wildlife Service 1998).

In response to the severe declines in these taxa and the Endangered Species Act, recovery plans for Owens Basin wetlands have been developed "to provide a means whereby the ecosystems upon which endangered and threatened species depend may be conserved" (U.S. Department of the Interior, Fish and Wildlife Service 1998:1). This plan calls for the creation of 16 conservation areas that will provide appropriate physical conditions (water level, chemistry, temperature, and plant growth) for fish survival as well as reduce the populations of deleterious alien species—mainly carnivorous fish that prey on native taxa. To identify habitat requirements, the recovery plan uses historic records on fish distribution and abundance as well as information from closely related species in nearby regions. Although recognizing the limitations of historic records, the authors of the plan note that these records "provide the *best* description of Owens Basin plant and animal communities prior to perturbations that caused the decline of many rare species" (U.S. Department of the Interior, Fish and Wildlife Service 1998:17, emphasis added).

Historic accounts are extremely useful for establishing certain baseline information on species distributions and abundances in recent times, but it is arguable whether they provide the "best description." Table 2.1 summarizes the primary historic accounts of Owens Valley fish. The first recorded observation by a natural scientist was in 1891, and the first long-term observations were carried out in the 1910s. Given that several non-native fish (catfish, carp, and salmonids) were already well established in the valley by this time, it is difficult to gage how much the native fish fauna and aquatic communities had changed. The first extensive collections and observations of native fish were in the 1940s and 1950s by University of Michigan ichthyologists, decades after the aquatic conditions had been drastically altered by Los Angeles County water-diversion projects. Moreover, a review of these studies reveals that most observers were working in limited areas and over brief periods of time (Table 2.1).

The zooarchaeological record can greatly expand our knowledge of Owens Valley fish by providing a substantially longer history of fish in the area. Recent archaeological projects in southern Owens Valley provide a faunal record that spans much of the Holocene. Further, extensive data on regional paleoenvironments (Benson et al. 1997; Smith and Bischoff 1997; Stine 1998) indicate that the aquatic system may have undergone significant change over the last several thousand years. These data can be used to suggest how fish have responded to these conditions and why some species are managing better than others under modern circumstances.

METHODS AND MATERIALS

Our study is based on analysis of fish remains from two archaeological projects in southern Owens Valley (Figure 2.1). The Alabama Gates sites are located within 2 km of the current river channel, about 15 km north of Owens Lake (Delacorte 1999). The Ash Creek sites are located west of the lake, near tributary streambeds or ancient embayments of the former lakeshore (Gilreath and Holanda 2000).

Seven sites from these projects provided fish remains, all of which were excavated and analyzed in similar ways (Butler 1999, 2000a). In the field, matrix was screened through 1/8-in (3.2-mm) mesh, except for small volumes during initial testing efforts that were screened through 1/4-in (6.4-mm) mesh. Bulk samples were collected in the field and wet sieved through nested 1/8-in and 1/16-in (1.6-mm) mesh in the lab (Alabama Gates—156 l; Ash Creek—488 l). Except for vertebrae, which were assigned to Catostomidae/Cyprinidae (sucker/minnow) because of morphological similarity, most skeletal elements could be assigned to at least taxonomic family. Maxillae and dentaries were used to identify sucker species, and pharyngeals were used to identify cyprinid species. Specimens were quantified using the number of identified specimens (NISP [Grayson 1984]). Vertebra diameters were measured (for the measurement used, see Casteel 1976) to estimate fish body length and changes in fish size, given the well-established relationship between vertebra size and body size. Because vertebrae from minnows and suckers cannot be distinguished, the measure provides a coarse-grained record of change in body size.

TABLE 2.1. Historic References to Fish in Owens Valley.

Year(s)	Observer	Comments	Source	Time and Duration of Visit
1859	Captain Davidson	"River is filled with a small fish, supposed to be a new species.... about 2 inches in length.... The Indians catch these fish in great quantities in sieve-like baskets.... These fish were confined to the river, I did not see any of them in its tributaries." (based on drawing provided, likely *Cyprinidon radiosus* [Owens pupfish])	Wilke and Lawton 1976:30	July–August
1872–1876	Anonymous	Numerous references to the raising of trout and initial stocking of Owens River tributaries in 1873	*Inyo Independent* (newspaper, various editions)	
891	C. H. Gilbert	Noted specimens of *Rutilus symmetricus* (or *Gila bicolor snyderi*, the Owens tui chub [Miller 1973]) from Owens Lake. Also noted that carp and catfish are common in the Lower Owens River and were found dead along the Owens Lake shore. Specimens of *Salmo mykiss agua-bonita* (golden trout) were collected in Cottonwood Creek, which drains into Owens Lake; according to Gilbert, these were transplants from Kern River.	Gilbert 1893	Unknown; all collecting localities were in the southern end of the valley, from Lone Pine south to Owens Lake

910s	C. H. Kennedy	"The fish, *Cyprinidon macularius* (= *C. radiosus,* Owens pupfish) was found in abundance in all the shallower parts of the sloughs and tule swamps at both Lone Pine and Laws. Every pool cut off by a gravel bar along the river contained a few of these little fish. They were apparently entirely comfortable in water not over 4 inches deep."	Snyder 1917:205	Unknown; probably multi-seasonal residence in the valley; most observations were made near Laws, about 5 km north of Bishop
		Noted that *Agosia robusta* (or *Rhinichthys osculus,* the dace) "is not common."	Snyder 1917:205	
		"Suckers (*Catostomus arenarius* = *C. fumeiventris,* Owens sucker) are common everywhere in the main river, usually lying in schools on the inflow side of pools."	Snyder 1917:202	
		Siphateles obesus (or *Gila bicolor snyderi,* the Owens tui chub) was collected, but observations on distribution and abundance were not provided.	Snyder 1917	
1933	J. H. Steward	Noted Paiute names for six fish, including a native minnow, two names for suckers (depending on age), two salmonids, and one type Steward could not match with a Euro-American name. "Fish occurred in Owens river, fresh-water sloughs, and the Sierra Nevada streams."	Steward 1933:250	Six weeks, summers of 1927 and 1928; short time in December 1931
1973	R. R. Miller	First systematic species accounts of Owens sucker and Owens tui chub, based on collections made by Snyder and University of Michigan ichthyologists.	Miller 1973	Unknown; collection localities indicate extensive travel throughout the valley, sampling the river, reservoirs, sloughs, irrigation ditches, etc.

Sites or portions thereof were assigned to one of four time periods based on radiocarbon dates, temporally diagnostic projectile points, and source-specific obsidian hydration ages: pre-7000 B.P., 3500–1350 B.P., 1350–650 B.P., 650–100 B.P. (Delacorte 1999; Gilreath and Holanda 2000). The earliest time period, marked by Great Basin Stemmed and Pinto series projectile points (Basgall and Hall 2001; Tuohy and Layton 1979), encompasses the broadest and least securely dated interval, owing to the lack of directly associated organic residues suitable for radiometric assay. Three radiocarbon dates were obtained from a buried soil just beneath the artifact-bearing stratum at one of the sites (INY-4554); these dates fall between 7780 ± 90 and 6740 ± 90 B.P. Obsidian hydration readings on more than 130 flakes and tools from the same deposit indicate that all of the artifacts are of broadly similar age, as evidenced by the low coefficient of variation in hydration (14 percent). It is reasonable to conclude, therefore, that most of the INY-4554 fish bone and other cultural remains date to the interval around or shortly after the two-sigma calibrated dates for the soil horizon (8960–7477 B.P.), as befits points of the Stemmed and Pinto series. Virtually identical dates are suggested for the other early archaeological components by statistically similar or slightly older obsidian hydration values and projectile point series.

RESULTS

A total of 1,371 fish remains was identified to at least family or sucker/minnow. Figure 2.2 shows the overall frequency of fish taxa with all the site assemblages aggregated. The sucker/minnow category has the most specimens, followed by the family categories—Catostomidae and Cyprinidae—and finally the species—tui chub, Owens sucker, and speckled dace. As Owens sucker was the only species in the family identified, all of the remains identified to the sucker family are presumably from Owens sucker as well. Of the 54 Cyprinidae (minnow) pharyngeals identified to species, 52 are from tui chub, and two are from speckled dace. Given the absolute dominance of tui chub in the deposits, it is reasonable to assume for analytical purposes that most of the specimens identified to Cyprinidae are from tui chub.

Remains of speckled dace are extremely rare, and no remains of Owens pupfish were identified. Because dace and pupfish are very small (maximum lengths = 100–150 mm), their scarcity could be explained by recovery bias, but this is unlikely given that large quantities of sediment were processed through 1/16-in mesh. Further, remains of very small fish were

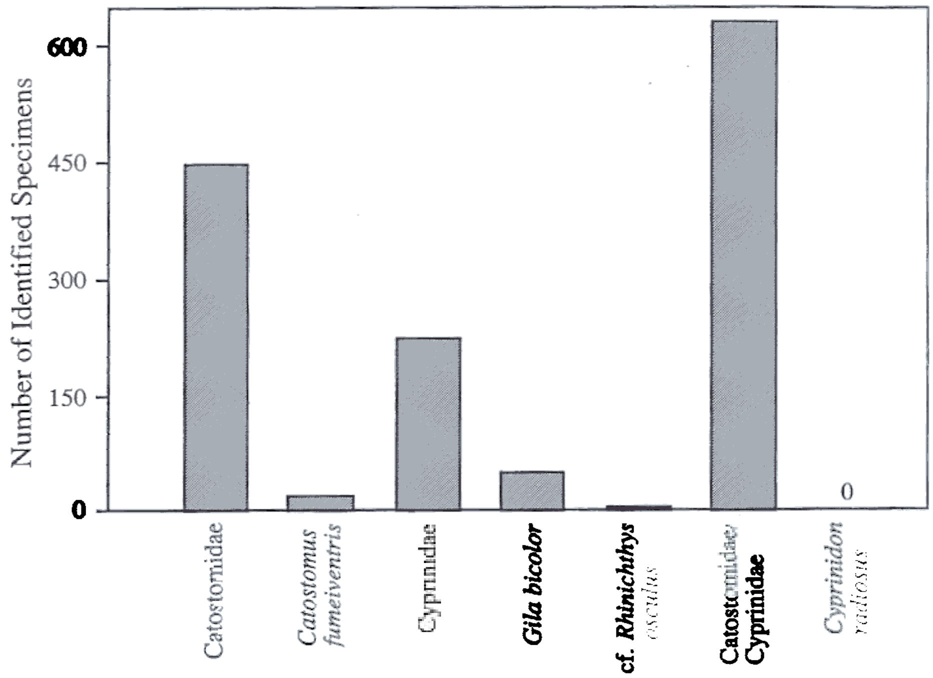

Figure 2.2. Fish taxonomic frequency, all sites combined.

recovered, judging by vertebra sizes (see below), just not those of dace and pupfish. Thus, the scarcity of dace and pupfish reflects something real about taxonomic representation in the archaeological deposits. There are several ways to interpret this pattern. The scarcity might indicate that aboriginal peoples did not target these fish or the habitats they occupied. The low frequency could also mean that one or both species were never abundant in the river system (or the habitats exploited by people). Perhaps both of these explanations are correct in part. Ethnohistoric descriptions emphasize that Native Americans used sieved baskets to catch small fish in the Owens Valley (Davidson, in Wilke and Lawton 1976; Steward 1933, 1941). As we discuss below, fish recovered from late-prehistoric contexts (< 3000 B.P.) are generally very small (< 200 mm long), and it is likely that most of them were caught using mass harvesting gear. If all species were occupying the same habitat, then one would expect that at least some individuals of all taxa would be captured by indiscriminate fishing techniques. As Owens sucker and tui chub absolutely dominate the assemblages, the implication is that dace and pupfish were not occupying the same habitats as the sucker and chub or that these very small fish occurred in negligible quantities in these habitats. The absence of pupfish and near absence of speckled dace suggest that these taxa were never very abundant in the lower river, where the archaeological assemblages were found. Faunal samples from other locations may substantiate this suggestion.

Temporal Patterning

Table 2.2 summarizes the temporal distribution of identified fish remains (NISP) across site components and time periods. Several points can be highlighted. Each time period has multiple components with fish remains, although the sample sizes in many components are extremely small. In our comparisons of taxonomic frequency over time, we include only those components with ≥ 30 NISP. Table 2.2 also shows a 3,500-year gap in faunal records (7000–3500 B.P.) that reflects the lack of dated archaeological deposits for this interval. Whether this gap is an artifact of archaeological sampling or some other phenomenon such as reduced human population density is unclear in Owens Valley and numerous Great Basin localities where middle Holocene occupations are often underrepresented.

To examine variation in sucker and chub abundance over time, we used a simple index (Σ Catostomidae NISP / Σ Cyprinidae NISP + Σ Catostomidae NISP) and calculated values for the five archaeological components with ≥ 30 NISP. All specimens identified to at least the family level were included. The index generates a value between 1.0 and 0, with higher values indicating a greater representation of sucker relative to minnow. Sucker absolutely dominates in the two early-period components (with index values close to 1.0); later components show a more even representation of sucker and minnow (Figure 2.3).

Another striking pattern is the change in vertebra diameter over time (Figure 2.4). Early deposits are dominated by large vertebrae (≥ 6 mm), and given that sucker dominates these early assemblages, the vertebrae indicate relatively large sucker. Later deposits are dominated by small vertebrae (typically 1–4 mm) and hence smaller fish, chub and sucker (Figure 2.4). For reference, fish > 300 mm long have vertebra > 5 mm wide; fish about 60 mm long have vertebra approximately 1 mm wide. Screen size is not responsible for the varying vertebra sizes, as fine-mesh samples from all site components were studied.

Search for Causes: Cultural

These patterns in taxonomic representation and body size could result from both cultural factors (human selection, technology) and environmental

TABLE 2.2. Frequencies (Number of Identified Specimens) of Fish Remains in Owens Valley Archaeological Sites and Components.

	Component						
Project Site	"Early" Pre 7000 B.P.	7000–3500 B.P.[a]	3500–1350 B.P.	1350–650 B.P.	1350–100 B.P.[b]	650–100 B.P.	Total
	253						253
	5						5
	7						7
				1	10	66	77
			2		26	4	32
			158			602	760
	134						134
				2			2

[a]There are no records for this time period.
[b]These materials are from stratigraphically mixed deposits.

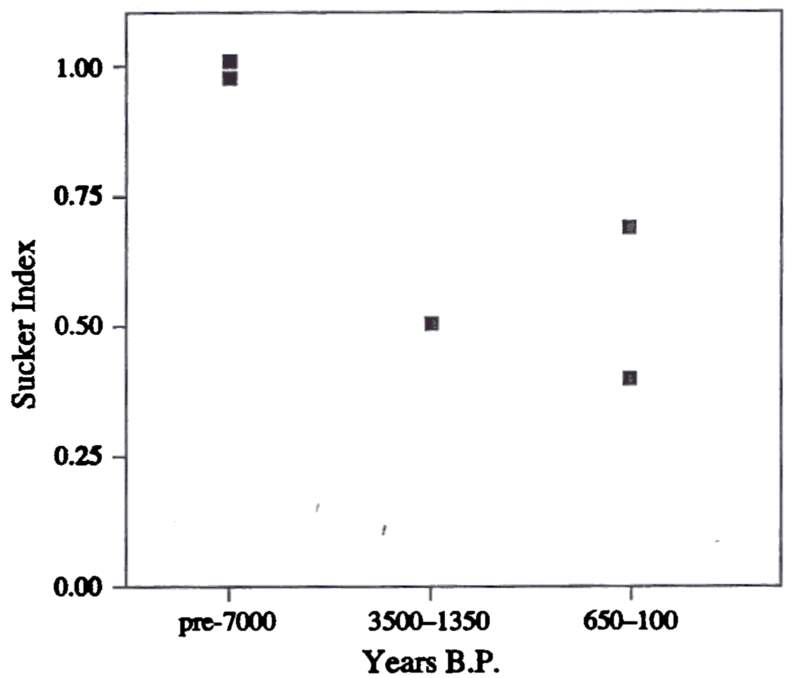

Figure 2.3. Change in relative frequency of sucker remains over time.

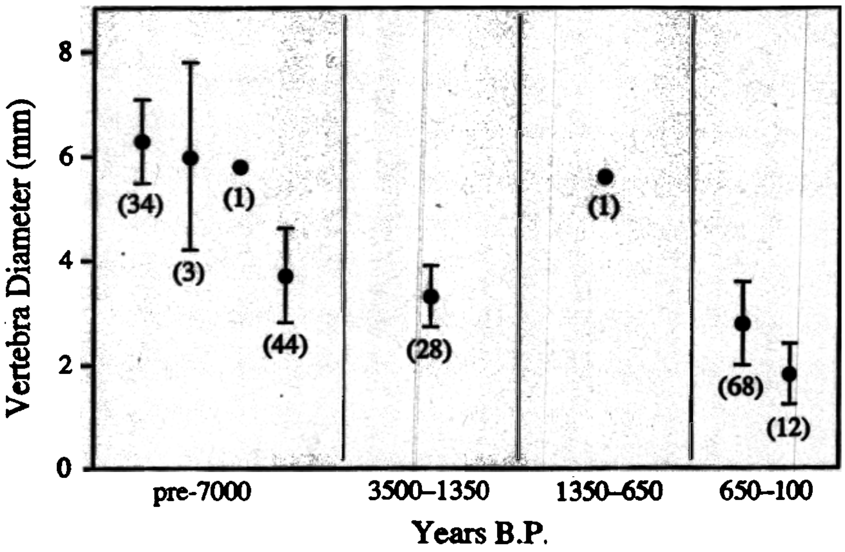

Figure 2.4. Change in vertebra diameter over time. Each error bar represents mean and standard deviation; sample size is in parenthesis.

factors (water conditions). The absence of small fish in the early period must result primarily from cultural practices because small fish were certainly present. This absence would be predicted by a prey-choice model derived from foraging theory, wherein highly ranked resources such as large fish are selectively targeted until their abundance declines to the point that pursuit of lower-ranked foods is of equal or better economic return (Broughton 1994, 1999; Grayson 2001). Given that prey rank is highly and positively correlated with body size, the model predicts that human foragers in Owens Valley would initially target large rather than small fish if the former were available in the river.

The same explanation and other cultural factors might also account for the late-prehistoric presence of small fish. Various zooarchaeological and paleoethnobotanical indicators point to more intensive subsistence practices and an expansion in late-prehistoric diet breadth (Bettinger 1976; Delacorte 1995, 1999). The adoption of mass harvesting technologies such as nets or basketry sieves would likewise result in the capture of primarily small fish, as documented in ethnohistoric accounts (Steward 1933; Wilke and Lawton 1976). Thus, cultural factors (predator–prey relationships, technology) probably account for some of the patterning.

But what is responsible for the absence of large fish late in the sequence? Were large fish common in the river and adjacent streams and marshes but not targeted by human foragers because of scheduling or other cultural constraints? Or were fish in the aquatic system simply smaller later in time? Delacorte (1999) believes that a shift from springtime fishing for mature fish during the spawning season to predominantly summer/fall fishing for juvenile fish and smaller species could have produced the archaeological pattern. Support for this hypothesis is provided by the seasonality of late-prehistoric components. Still, if large fish were present in the aquatic system, they probably should have been taken to some extent, as the prey-choice model predicts. Because the relatively large fish in early archaeological contexts are Owens sucker, the question more specifically relates to body size changes in sucker. Aquatic habitats in the Great Basin in general and Owens Valley in particular have undergone significant change over the last several thousand years, and it is reasonable to think that such changes have affected not only species abundances but fish size as well (Smith 1981).

Search for Causes: Environmental Change

The end of the Pleistocene brought increasingly arid conditions and the disappearance of the huge pluvial lakes that once covered much of the Great Basin. In Owens and nearby valleys, records of change in aquatic habitats come from studies of lake-bed cores and relict tree stumps. Given that most of the water in eastern California lakes comes from Sierran stream runoff, major fluctuations in lake level also monitor changes in the extent and size of riverine and other aquatic habitats throughout the valleys. Benson et al.'s (1997) oxygen isotope analysis of an Owens Lake core establishes periods when the basin was closed (low flow, dry interval) and open (high flow, wet interval—wherein water overflowed the Owens Basin, filling pluvial lakes to the south and east). Owens Lake experienced four extremely dry, closed-basin intervals between 15,800 and 6,700 years ago that were preceded by wetter episodes (all ages are calibrated). Dry intervals centered on dates of 15,100, 13,200, 12,200, and 11,100 years ago. Following the last dry interval, the basin remained closed, with the lake itself desiccating completely about 6,700 years ago. Support for this desiccation period comes from Bischoff et al.'s (1997) work on another Owens Lake core. Both studies suggest that conditions became wetter after the desiccation period. This period of hyperaridity coincides with numerous western Great Basin paleoclimatic records (macrobotanical, pollen, tree line fluctuations, relict stumps) that chronicle a significant dry/warm interval from about 7,500 until 4,500 years ago (Grayson 1993).

Lake level fluctuations over the last 5,000 years have been reconstructed by Stine (1990, 1994a, 1994b, 1998), who has dated relict tree stumps found in growth position on former lakeshores, 10 m or more below historic lake levels. Stine's detailed studies of multiple basins indicate that lakes have undergone dramatic changes in water level—from a Holocene high stand 3,800 years ago to periods of extremely low levels or complete desiccation. The two lowest lake levels occurred between A.D. 900–1100 and A.D. 1200–1350, periods of extreme drought, for which Stine (1998) estimates inflow was less than 68 percent of modern levels (averaged from the years 1937–1979). A stump from Owens Lake located only 3 m above the lowest point on the lake bed dates to A.D. ~1020 and indicates that the lake was extremely shallow at that time (Stine 1998). The second-highest stand of the Holocene was reached about 375 years ago. The close correspondence of the dates for lake level changes across multiple basins (Tahoe, Mono, Owens), the absence of geomorphic explanations for the changes, and the corroborating evidence for paleoclimatic changes from other data such as tree rings (Graumlich 1993; Hughes and Graumlich 1996; LaMarche 1974) strongly argues for a unifying explanation: changes in precipitation, changes in evapotranspiration, or both (Stine 1998).

These records indicate that Owens Basin wetlands (river, tributaries, marshes, lake) have changed dramatically in size, depth, chemistry, and flow conditions over the last 15,000 years. The presence of fish in archaeological deposits predating 7000 B.P., and from 3500 B.P. to historic times, demonstrates that fish were able to adjust to these changing conditions. The nature of those adjustments was undoubtedly complex, including changes in productivity that would have affected the overall abundance and distribution of fish across the basin. We also suggest, however, that different species of fish would have responded differently to habitat changes, owing to differences in their life history strategies, and it is to these issues that we turn next.

Evolutionary ecologists long have recognized wide variation in life history strategies among organisms, including growth rate and overall body size attained, age at first reproduction, number of offspring, and reproductive cycles (MacArthur and Wilson 1967; Pianka 1970; Ricklefs 1979). In recognition of these factors, researchers have suggested that in more stable environments, populations live at limits imposed by the resources (or carrying capacity, *K*). Conversely, in more fluctuating environments, where populations periodically crash because of catastrophic events, adaptations that increase intrinsic population growth *(r)* are advantageous. In a catastrophic event, organisms die without regard to their genotype; in environments subjected to periodic fluctuations in temperature or moisture, selection favors rapid growth, early age of maturation, and small body size. In short, *r*-selected traits are favored in unstable environments, and *K*-selected traits are favored in stable settings.

Smith (1981) has used this distinction in a study of Great Basin fish and suggests that life history traits were strongly correlated with *size* of aquatic habitat: the larger the creek, river, or lake, the larger the fish and the older the fish at first spawning. Smith argues that habitat size is a good predictor of life history characteristics because of the link between environmental stability and habitat size. If all other variables are equal, then the larger the habitat, the more stable it is. Smith also found a strong positive relationship between body size and size of aquatic habitat, which he thought resulted from larger habitats being more stable.

Comparative life history data for tui chub and other suckers in California and Nevada show that the chub is more an *r*-strategist and that suckers are more *K*-strategists. *Catostomus fumeiventris* has received little study but is generally thought to resemble *C. tahoensis* (Tahoe sucker) in life history traits (Moyle 2002). Tui chub mature at smaller sizes and younger ages than the suckers most like Owens sucker. Also, the maximum size attained by chub is usually smaller than that reached by suckers. Historically, chub have thrived in the fluctuating environments of the western Great Basin, being the most abundant species in the large, shallow Harney Lake of southeastern Oregon and Eagle Lake of northeastern California. The ability of chub to "take advantage" of temporary improvements in habitat was illustrated in the 1980s when exceptionally high water flows into the Carson Sink of northeastern Nevada created vast shallow lake and marsh habitats. This led to a tremendous population explosion of tui chub. Subsequent declines in water level resulted in the mass death of an estimated seven million fish (Rowe and Hoffman 1987). Tui chub is the dominant fish in archaeological deposits dating to the last 3,000 years in this area, suggesting chub's prominence in these settings for an extended period (Butler 1996). Historically, the primary sucker of the Lahontan system in the western Great Basin, the Tahoe sucker, is less abundant in aquatic systems, and this at least indirectly suggests that suckers are not as successful as chub in highly fluctuating environments.

Smith's (1981) notions and the life history observations summarized in the preceding paragraph provide a basis on which to predict how chub and sucker would respond to changes in aquatic habitat over the last several thousand years. We predict that sucker would thrive in expanded or stable habitats and that tui chub would be favored in more constricted or fluctuating habitats or if both conditions obtained. As well, we predict that fish body size would decline with the constriction of aquatic habitat owing to the decline in stability.

Testing of the first prediction cannot be rigorous because we lack sufficient temporal resolution. For example, the earliest archaeological period spans several thousand years before 7000 B.P., and thus the fish record for this time cannot be readily compared with the detailed environmental reconstructions. Nevertheless, in expanded aquatic habitats of the Late Pleistocene/Early Holocene we find evidence for large Owens sucker, as expected. Toward the end of the Holocene, when aquatic habitats were reduced relative to Late Pleistocene–Early Holocene conditions and were subject to alternating periods of wetter and drier conditions, we find a more balanced mix of chub and sucker of generally smaller body size.

We can test the second prediction more rigorously using historic data on fish size. If the late-prehistoric pattern for small size is environmentally controlled—fish were relatively small because of habitat constraints—then small size should continue into the historic period. Alternatively, if small size reflects cultural selection—large fish were in the water system but not targeted for capture—then large fish should be present in the historic period.

Snyder (1917) lists individual body lengths of sucker and tui chub obtained from the Owens River drainage in the 1910s. These fish apparently were collected near the town of Laws, about 5 km northeast of Bishop. Sample sizes were small (n = 10 for each taxon), but the results are consistent with the hypothesis that modern chub and sucker are small. Sucker body length averaged 154 ± 16 mm, and chub body length averaged 89 ± 8 mm.

More recent collections reported by Miller (1973) include over 1,600 individuals each of chub and sucker. Collection dates are listed for some fish and indicate that they were caught in the 1940s and 1950s. Fish were collected throughout Owens Valley—from the main river channel, springs, irrigation ditches, sloughs, and reservoirs constructed for water diversion. Miller lists the range in body size (standard length) for each collection of fish, not individual specimens, precluding the calculation of summary statistics. Tui chub were consistently small, with a maximum standard length of 180 mm, and most fish were considerably smaller than this (Figure 2.5). The body size of Owens sucker is extremely variable, with some fish attaining lengths of over 400 mm (Figure 2.6). Important to our purpose, the largest body sizes of Owens sucker are from fish that had access to a

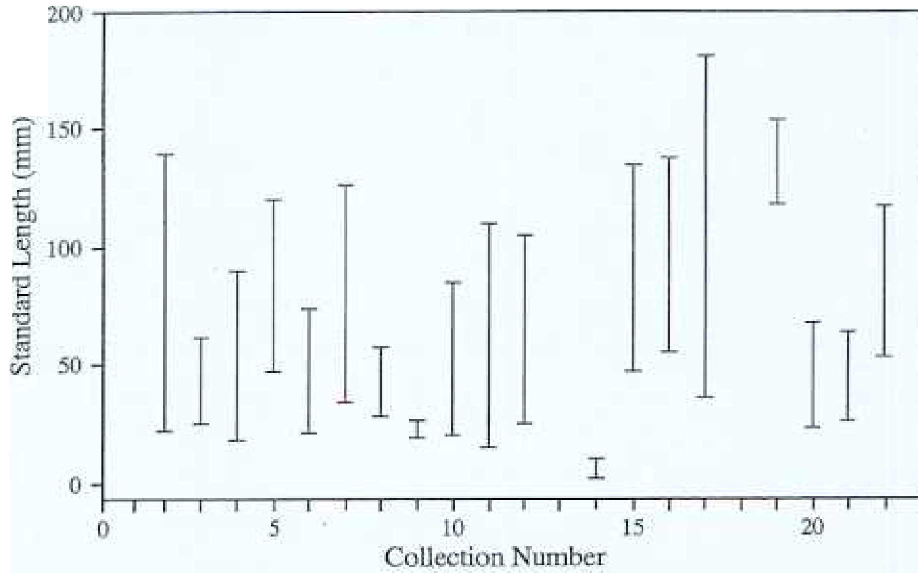

Figure 2.5. Standard length (mm) of tui chub *(Gila bicolor)* in 20th-century collections (*N* = 1,844 fish; bars are maximum–minimum size per collection).

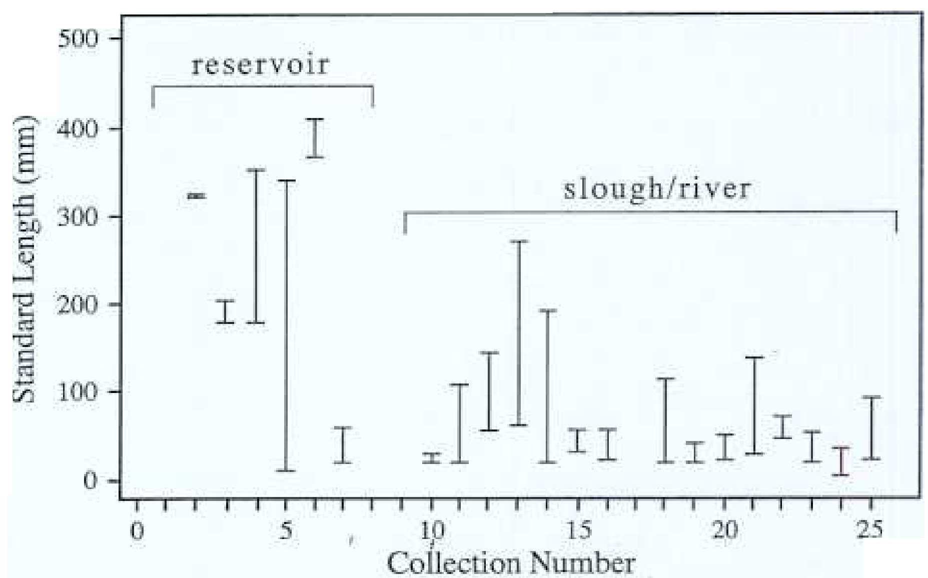

Figure 2.6. Standard length (mm) of Owens sucker *(Catostomus fumeiventris)* in 20th-century collections (*N* = 1,692 fish; bars are maximum–minimum size per collection).

large reservoir (Crowley Lake) during their yearly life cycle (Figure 2.6). The maximum size of sucker captured from sloughs and the Owens River itself is < 300 mm, and most fish are much smaller than this.

The large suckers found in association with reservoirs are the exceptions that prove the rule. Suckers attain relatively large sizes in modern times because they have access to reservoirs and thus are artifacts of 20th-century water projects. This supports our prediction that fish size (in historic and prehistoric times) has been constrained by the size of aquatic habitats. In turn, this result is consistent with the suggestion that the general trend toward smaller body size, from the early to the later periods (Figure 2.4), results from reduction in the size of aquatic habitat.

IMPLICATIONS FOR FISHERIES MANAGEMENT

Our results have two main implications for modern fishery issues in the Owens Valley. First, they may explain why Owens sucker, of all the native fish, is surviving relatively well in the valley today. Its success may be linked to the species' ability to thrive in artificially created lakes. Such lakes provide relatively large, stable habitats, which favor *K*-selected species such as Owens sucker. While not specifying the cause, Moyle recently commented on the relative success of the sucker in Owens Valley, noting that the fish "showed some capacity to adjust to the presence of nonnative fishes" (2002:195). Varying life histories may explain why certain fish are coping well with major changes wrought by modern water-use practices and fish introductions.

Second, our historical perspective allows us to isolate particular causes for modern declines in native fish. Biologists note two main causes for the declines: the significant loss of aquatic habitat associated with large-scale water-diversion projects and the introduction of alien species, mainly predaceous fish (U.S. Department of the Interior, Fish and Wildlife Service 1998). Paleoenvironmental records for Owens Valley clearly show, however, that aquatic habitats underwent major fluctuations over the last 15,000 years. Owens Lake has been desiccated or nearly so at least twice in the last 6,700 years; at other times conditions were much wetter, and the basin contained more wetlands than are known for the historic period. The zooarchaeological record demonstrates that fish inhabited the basin over this entire time and that they adjusted to these changes. That Owens Valley fish were able to cope with significant loss in habitat in ancient times (by finding refuge in available wetlands or reducing body size) suggests that these fish should have been capable of adjusting to habitat changes caused by 20th-century water-diversion projects. History did not, however, prepare native fish for introduced predators. Our study supports the position that nonnative predator fish are primarily responsible for modern declines in native fish. Unless more efforts are made to reduce or eliminate these alien fish from the critical habitat, the native species are probably doomed to extinction.

FUTURE STUDIES

Additional zooarchaeological samples from throughout the basin should be studied to develop a comprehensive record of fish distribution and abundance. The resulting data will allow us to track faunal changes that might be linked to environmental versus cultural changes. One archaeological site that merits particular attention is Fish Slough Cave, located next to Fish Slough, an extensive riparian habitat just north of the Owens River near Bishop (Figure 2.1). Archaeological projects carried out there in the early 1990s suggest that most cultural remains date between 1350 and 100 B.P. (Nelson 1999). Over 300 human coprolites were recovered, and faunal and floral preservation within them is excellent. Fish remains are common but have received little detailed analysis (Nelson 1999). The fish record here is important because it spans Stine's period of purportedly extreme drought (during the so-called medieval climatic anomaly). It should be possible in this context to obtain high-resolution radiocarbon dates of individual coprolites and to establish a precise record of fish response to what were likely significant changes in habitat.

If study of the Fish Slough Cave zooarchaeological collection (or others from the Owens Valley) produces results similar to those reported here, then ecologists will have strong evidence of baseline ichthyofaunal conditions. Such information can then be used to modify the existing recovery plan, and appropriate actions can be taken. By themselves, the data and analyses we have presented here indicate that management actions should minimally comprise significant reduction of alien predatory fish if a pre-19th-century ecosystem constitutes the desired baseline conditions. Our study also suggests that native fish taxa can withstand major fluctuations in local water levels, provided that they are not under additional stresses such as predation by alien species. In our view, this is an important bit of information for conservation biologists to have as modern Californians continue to divert water to their own uses.

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