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# Fish Remains from Homestead Cave and Lake Levels of the Past 13,000 Years in the Bonneville Basin

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**A late Quaternary ichthyofauna from Homestead Cave, Utah, provides a new source of information on lake history in the Bonneville basin. The fish, represented by 11 freshwater species, were accumulated between ~11,200 and ~1000 $^{14}$C yr B.P. by scavenging owls. The $^{87}$Sr/$^{86}$Sr ratio of Lake Bonneville varied with its elevation; $^{87}$Sr/$^{86}$Sr values of fish from the lowest stratum of the cave suggest they grew in a lake near the terminal Pleistocene Gilbert shoreline. In the lowest deposits, a decrease in fish size and an increase in species tolerant of higher salinities or temperatures suggest multiple die-offs associated with declining lake levels. An initial, catastrophic, post-Provo die-off occurred at 11,300–11,200 $^{14}$C yr B.P. and was followed by at least one rebound or recolonization of fish populations, but fish were gone from Lake Bonneville sometime before ~10,400 $^{14}$C yr B.P. This evidence is inconsistent with previous inferences of a near desiccation of Lake Bonneville between 13,000 and 12,000 $^{14}$C yr B.P. Peaks in *Gila atraria* frequencies in the upper strata suggest the Great Salt Lake had highstands at ~3400 and ~1000 $^{14}$C yr B.P.** © 2000 University of Washington.

*Key Words:* **fish remains; lake-level fluctuations; Lake Bonneville; Great Salt Lake; terminal Pleistocene; Holocene.**

## INTRODUCTION

Although the histories of Lake Bonneville and its Holocene remnant, Great Salt Lake, have been studied intensively for more than a century (Gilbert, 1890) and the fluctuations of those lakes (Fig. 1) have been used to evaluate global-scale climatic changes and forcing mechanisms (Benson *et al.*, 1992; Oviatt, 1997), certain periods of those histories remain poorly understood. The timing of the regression of Lake Bonneville from the Provo shoreline, at ~14,500 $^{14}$C yr ago, until the final retreat from the Gilbert shoreline at the close of the Pleistocene is one of those periods. Based on studies of shoreline features and sediment stratigraphy, it has been suggested that Lake Bonneville declined to elevations approaching those of the modern Great Salt Lake soon after 13,000 $^{14}$C yr B.P. Shortly after 12,200 $^{14}$C yr B.P., the lake rose again, forming the Gilbert shoreline, peaking between 10,900 and 10,300 $^{14}$C yr B.P. (Thompson *et al.*, 1990; Benson *et al.*, 1992; Oviatt *et al.*, 1992). The plant macrofossil record, however, indicates that summer temperatures and evaporation rates were substantially depressed between 13,000 and 11,000 $^{14}$C yr B.P., and it suggests that a larger lake would likely have existed at this time (Rhode and Madsen, 1995). The Holocene history of Great Salt Lake is based on limited shoreline and core data and remains incompletely understood as well (Mehringer, 1985; McKenzie and Eberli, 1987; Currey, 1990).

Information on lake history can be obtained from analyses of fossil fish sequences (e.g., Hubbs and Miller 1948; Bachhuber 1989; Schmitz *et al.*, 1991), but this has not been possible in the Bonneville basin, until now, due to a meager late Quaternary fish record in the region (Smith *et al.*, 1968). In this paper, we present the species composition, size structure, and $^{87}$Sr/$^{86}$Sr ratios of the precisely dated ichthyofauna from Homestead Cave, and we discuss their implications for terminal Pleistocene and Holocene lake history in the Bonneville basin.

## HOMESTEAD CAVE

Homestead Cave is located several kilometers west of Great Salt Lake on a northwestern spur of the Lakeside Mountains (Fig. 2). The cave sits at an elevation of 1406 m, ~100 m below the Provo shoreline of Lake Bonneville and ~90 m above the Gilbert shoreline (Fig. 3). In 1993 and 1994, we

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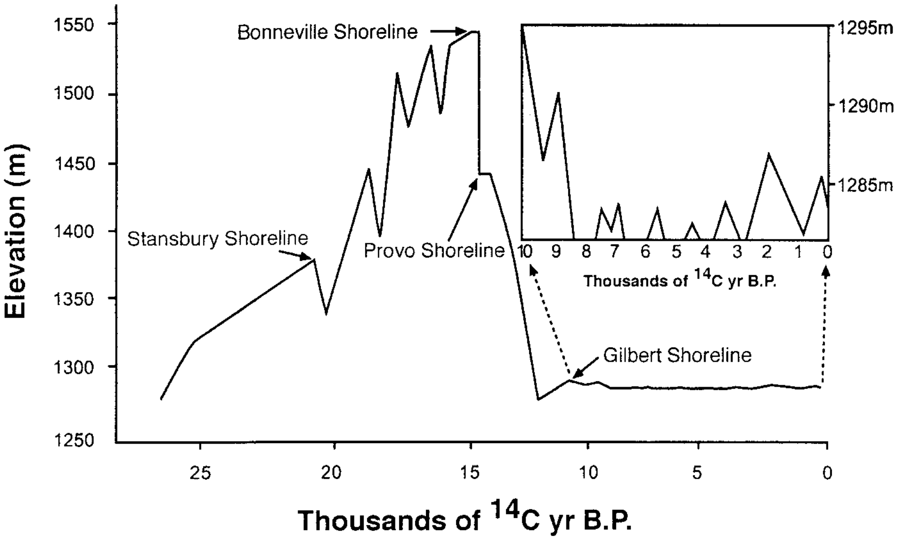

**FIG. 1.** Late Quaternary shoreline history of Lake Bonneville and the Great Salt Lake (adapted from Oviatt *et al.*, 1992; Oviatt, 1997; Murchison, 1989; McKenzie and Eberli, 1987).

excavated a 1-m$^3$ sample column in the rear cave-floor deposits (Fig. 4). The well-defined deposits were separated into 18 excavatable strata. Materials excavated from the column were passed through a series of 1/4-in (6.4-mm), 1/8-in (3.2-mm), and 1/16-in (1.6-mm) screens in the lab. Twenty-one $^{14}$C assays were derived from the deposits (Table 1). The coherency of the $^{14}$C results suggests that the deposits were laid down sequentially between ~11,300 and ~1000 $^{14}$C yr B.P.

Fish remains were heavily concentrated in stratum I of the cave. Stratum I consists primarily of degraded organic material, including vast quantities of small vertebrate bone (Grayson, 1998; Madsen, 2000). Stratum I was removed as single layer because the numerous microlaminae evident in the unit could not be confidently separated. However, the laminated nature of the stratum I sediments together with a difference in more than a thousand years in radiocarbon ages from the top to the bottom of the stratum (Table 1) suggest it is actually composed of multiple depositional events. To increase the stratigraphic resolution within stratum I, sediment samples of the upper and lower halves of the stratum were collected from the profile and samples were also taken from the upper and lower 10 cm of stratum I where it was thickest. Stratum Ia is the arbitrarily defined lower half of stratum I while stratum Ib is the arbitrarily defined upper half. The very small numbers of fish remains above stratum I suggest minimal bioturbation. Four radiocarbon assays on individual fecal pellets collected from the lowest 5 cm of stratum Ia, directly overlying bedrock, are statistically indistinguishable and provide a weighted average of 11,201 ± 76 $^{14}$C yr B.P. Fecal pellets taken directly from the upper 5 cm of stratum Ib provided ages of 10,350 ± 80 and 10,160 ± 85 $^{14}$C yr B.P. The undisturbed microlaminae in stratum I suggest the age of these fecal pellets can be used date associated faunal remains.

## TAXONOMIC SUMMARY AND DEPOSITION OF THE HOMESTEAD CAVE FISHES

A total of 14,866 fish specimens representing 11 freshwater species were identified from the cave (Table 2; Figs. 5 and 6). Four of the identified species (cf. *Salvelinus confluentus*, *Prosopium abyssicola*, *Richardsonius balteatus*, and *Catostomus discobolus*) represent first records for Lake Bonneville (Broughton, 2000a, 2000b). Eight of the represented species occur in Bear Lake, a cold, oligotrophic, high-elevation body of water on the Utah–Idaho border, and four of them are now endemic to that lake (Sigler and Sigler, 1996).

Several lines of evidence suggest that owls were the agents that deposited the cave fauna: owl pellet cones were observed on the floor of the cave when the excavation began; the deposits contain numerous owl pellets; and many of the bones themselves, including fish bones from stratum I, still have pellet material adhering to them. Evidence for human and carnivore involvement in the accumulation of the fauna is sparse, and there is no evidence for water-laid deposits (Grayson, 1998; Madsen, 2000).

Of the raptor taxa identified in the lower strata (I–III) of the deposit (Livingston, 2000), only two routinely roost and nest in deep, open caves, the owls *Tyto alba* and *Bubo virginianus*. Although these owls mainly eat small mammals, they will scavenge fish carcasses and take fish exposed in very shallow water (Gallup, 1949; Errington *et al.*, 1940; Klippel, W., personal communication, 1998). The maximum prey size that *Bubo virginianus*, the larger of the two species, can carry whole is ~1.5 kg (Marti, K., personal communication, 1997). Many of the fish specimens recovered from the cave come from very large individuals (>~2.6 kg estimated live weight; Broughton, 2000b). This evidence suggests that the owls did

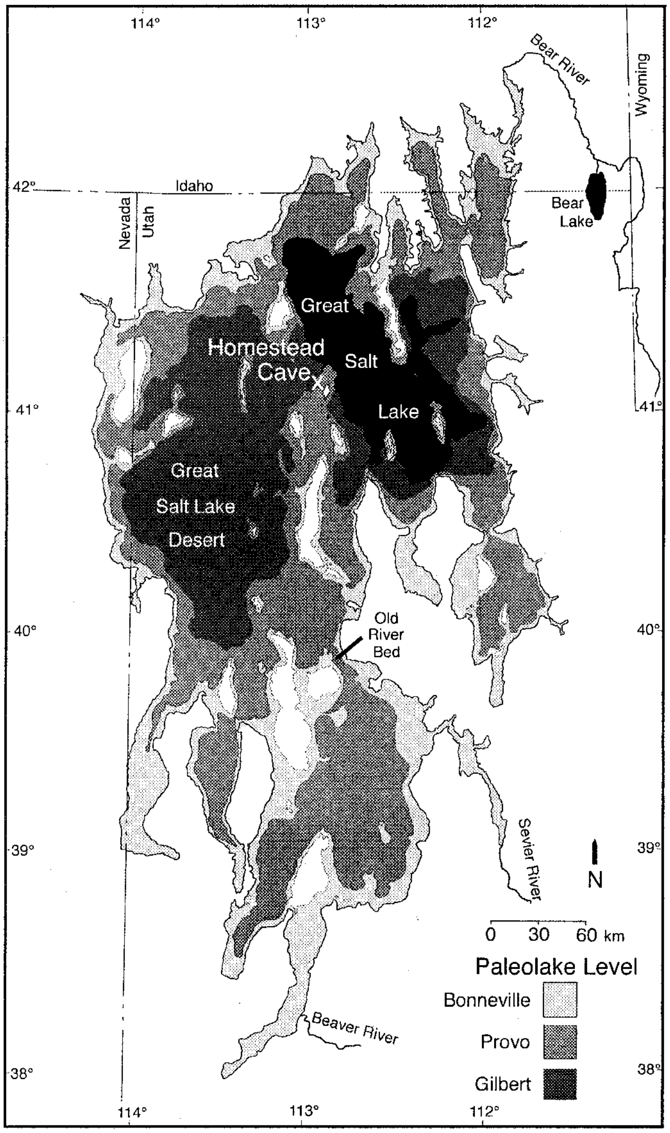

**FIG. 2.** Map of the Bonneville basin showing major paleolake levels and the location of Homestead Cave (adapted from Currey 1990, p. 202).

not take such fish whole, out of deep water, but instead scavenged them as parts.

The maximum distance from roost to foraging areas reported for the owls is 5.6 km (Marti, 1992; Smith, 1971). Thus, aquatic habitats that supported fish, and that at least occasionally experienced substantial die-offs, likely existed within a radius of ~6 km or less from the cave during the periods of fish-bone deposition.

## STRONTIUM RATIOS, HOMESTEAD FISHES, AND PALEOLAKE LEVELS

Because $^{87}$Sr/$^{86}$Sr ratios of lake water are identical to the ratio of any carbonate (e.g., tufa, shell) or apatite (e.g., fish bone) growing in that water, the $^{87}$Sr/$^{86}$Sr ratio of paleowaters can be reconstructed from analysis of these materials. To reconstruct paleolake levels from $^{87}$Sr/$^{86}$Sr ratios of fossil material requires either (1) lake systems with multiple basins, each fed by rivers with unique $^{87}$Sr/$^{86}$Sr ratios, as in Lake Bonneville, or (2) inflowing rivers in which the $^{87}$Sr/$^{86}$Sr ratios change with recharge fluctuations. The main rivers are the Bear ($^{87}$Sr/$^{86}$Sr = 0.71926) in the north and the Beaver/Sevier ($^{87}$Sr/$^{86}$Sr = 0.7074) in the south (Jones and Faure, 1972; Bouchard, 1997). Analysis of tufas and shell from the high (Provo and Bonneville) shorelines shows that the $^{87}$Sr/$^{86}$Sr ratios of paleolake waters in an integrated Lake Bonneville were 0.7114–0.7119, which represents some average of all values of rivers feeding into the lake (Quade, 2000a).

Lake Bonneville segmented during the terminal Pleistocene, when it dropped below the Old River Bed threshold at 1390 m, and the $^{87}$Sr/$^{86}$Sr ratio of at least some component water bodies shifted toward the value of local river inputs. This "splitting" event is clearly recorded in the $^{87}$Sr/$^{86}$Sr ratios of carbonates associated with the smaller terminal Pleistocene lake in the southern basin. Shells from the southern basin filled by paleolake Gunnison have low ratios (0.7098), consistent with input from the Sevier/Beaver Rivers (Fig. 7). Tufa and shell from the northern basin filled to the Gilbert shoreline in the latest Pleistocene give ratios of 0.7120–0.7144. Mass balance estimates from modern rivers suggest that these elevated ratios are not the result of isolation of the northern basin from the southern rivers (Bouchard, 1997). Instead, the $^{87}$Sr/$^{86}$Sr ratio of the Bear River, the main source of Sr in the northern basin, may have shifted toward higher values as the lake dropped. While the exact causes are unclear, the key point here is that low (Gilbert) lake levels in the northern basin yield consistently higher $^{87}$Sr/$^{86}$Sr ratios (0.7120–0.7144) than those of the higher, integrated lake (0.7114–0.7119) (Quade, 2000a).

The $^{87}$Sr/$^{86}$Sr ratios of six stratum I fish specimens from the cave pinpoint the level of the lake in which the fish lived. All the fish analyzed, including *Catostomus ardens, Gila atraria,* and *Oncorhynchus* cf. *clarki* returned $^{87}$Sr/$^{86}$Sr ratios between 0.7125 and 0.7129 (Quade, 2000b; Fig. 7). These values are markedly different from those of high-shoreline tufas and shell (0.7114–0.7119) and average slightly lower than values from these materials derived from the low-elevation, Gilbert shoreline. The presence of freshwater fish taxa with such high $^{87}$Sr/$^{86}$Sr ratios implies the presence of a shallow but freshwater lake within the raptor foraging radius (~6 km) of the cave between ~11,200 and ~10,400 $^{14}$C yr B.P.

## CHANGE IN FISH SIZE AND TAXONOMIC ABUNDANCES

### *Fish Size*

For intermountain fishes, Smith (1981) made a model linking intraspecific variation in life history strategies to local

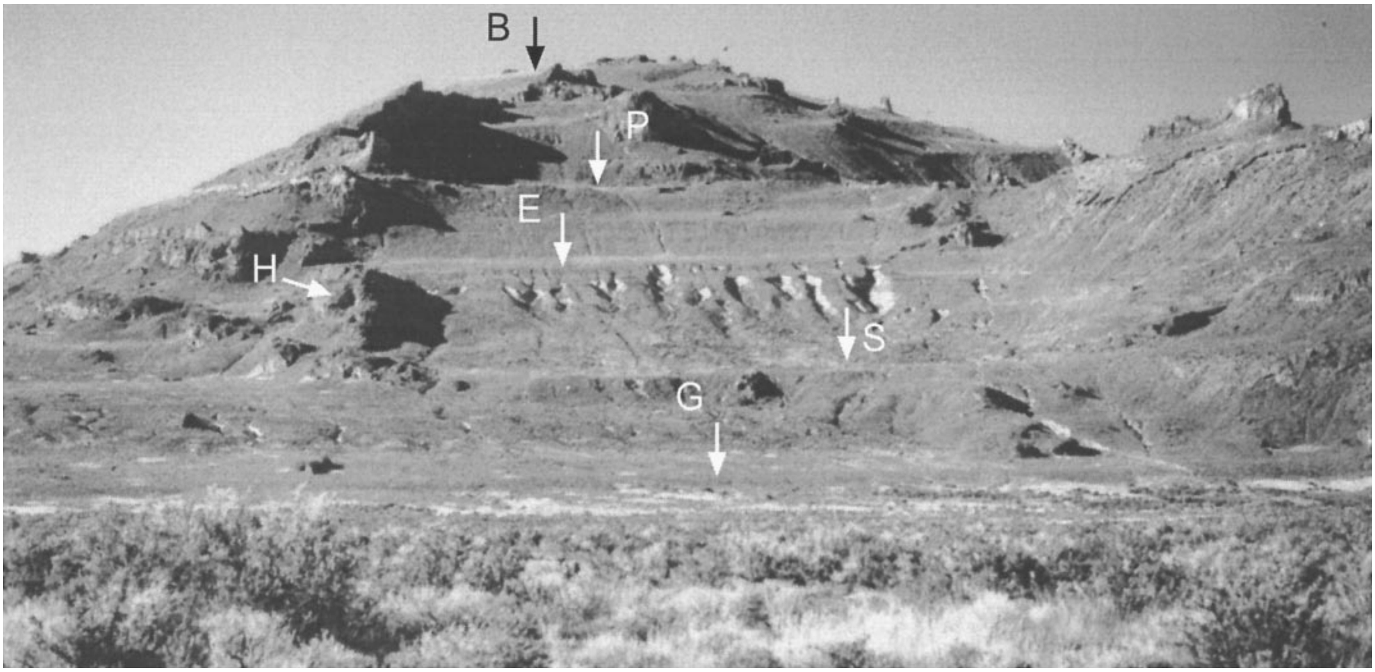

**FIG. 3.** View of Homestead Cave from the top of the highest Holocene shoreline of Great Salt Lake showing: (B) the Bonneville shoreline, (P) the Provo shoreline, (E) erosion channels in a post-Provo regressive shoreline, (H) Homestead Cave, (S) the Stansbury shoreline complex, and (G) the Gilbert shoreline.

regimes of habitat stability and adult mortality. This model, consistent with general predictions from life history theory (e.g., Roff, 1984; Charnov, 1993), has implications for change in fish body size in populations that endure high rates of adult mortality:

> Many intermountain minnows, suckers, and trouts are selected locally for large size by increased adult survival and consequent late reproduction in large habitats. Annual fluctuations that reduce habitats seasonally, thus causing heavy mortality, lead to persistence of phenotypes that reproduce early at the expense of later growth . . . . When adult mortality is low individuals leave more descendants by growing larger and producing more young over several seasons (Smith, 1981, pp. 126, 162).

Smith documented positive relationships between habitat size, as a measure of environmental stability, and maximum adult size in many western fish species, including some of the cypriniform taxa represented at the cave, namely, *G. atraria* and *Catostomus discobolus.*

Cypriniformes vertebrae identified from stratum Ia and stratum Ib were selected for analysis of size change (Table 3). The maximum diameters of vertebral centra, as a measure of size, differ distinctively between stratum Ia and Ib; the later deposit (Ib) has a smaller maximum size and exhibits a significantly smaller mean size than stratum Ia (Mann–Whitney $U = 8546.5$, $P < .05$).

Because size changed in the direction predicted for conditions of elevated adult mortality, the fauna probably accumulated over a period of time long enough for size change to occur, that is, over several episodes of substantial mortality. This suggests the fauna as a whole resulted from not one but several die-off events.

### *Relative Taxonomic Abundances*

Lake-level fluctuations may also explain changes across the stratum I deposits in the relative abundances of species that can and cannot tolerate elevated water temperature or salinity. Of the taxa represented at the cave, only *O. clarki* and *G. atraria* are known to tolerate waters with moderate salinities and these taxa are significantly overrepresented in stratum Ib, compared to stratum Ia ($X^2 = 4.31$, $P < .05$; Table 4). The fishes of the cave that are tolerant of warm ($>\sim$27°C) water temperatures, *C. ardens* and *G. atraria,* are significantly overrepresented in stratum Ib as well ($X^2 = 7.41$, $P \ll .01$; Table 4).

These changes are in the direction expected of a lake level decline and are consistent with other data that suggest the assemblage resulted from die-offs. That such a change is registered in the fauna also suggests that the assemblage accumulated over a period of time, instead of a single, instantaneous die-off event. And insofar as the faunas from stratum Ia and Ib resulted from separate die-offs, the presence of all fish taxa in both units implies that, following the initial die-off, the rebound or recolonization involved the entire Lake Bonneville fish fauna. The overrepresentation of fishes more tolerant of high temperatures or salinities in stratum Ib suggest those taxa were relatively more successful at reinvading the lake.

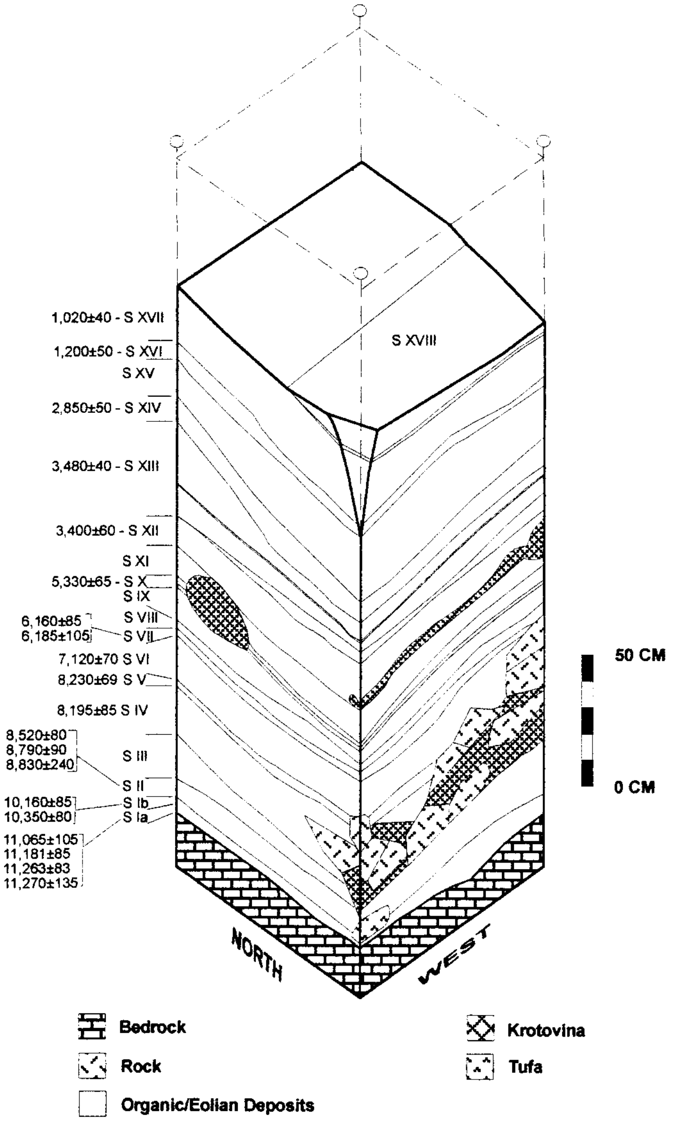

**FIG. 4.** Block diagram of Homestead Cave sample column stratigraphy showing the north and west profiles, strata designations, and radiocarbon ages.

## THE CHRONOLOGY OF TERMINAL PLEISTOCENE AND HOLOCENE LAKE-LEVEL FLUCTUATIONS IN THE BONNEVILLE BASIN

### *Lake-Level Fluctuations of Terminal Pleistocene Lake Bonneville*

Fish remains are clearly concentrated in stratum I (Table 5). They account for over 26% of the assemblage in stratum I but comprise, in most cases, far less than 1% of the fauna in the higher strata. To further pinpoint the stratigraphic break in the cave deposits after which fish remains become far less abundant, we examined the distribution of fish materials within stratum I itself. In the bulk sediment sample taken from the lower 10 cm of the 30-cm-thick stratum I, fish comprise 23.5% (807 of 3,434 specimens) of the entire vertebrate faunal assemblage. By contrast, fish comprise only 0.02% (10 of 3,896 specimens) of the vertebrate materials from the upper 10 cm—a figure very similar to the relative abundance of fishes throughout the rest of the column. The difference in the frequencies of fish and non-fish vertebrate specimens across these divisions is significant ($X^2 = 955.34$, $P \ll .0001$). Fish remains are essentially absent from the upper one-third of stratum I and are confined to stratum Ia and the *lowest* microlaminae of stratum Ib. The die-offs of Lake Bonneville's fishes thus appear to have begun ~11,200 $^{14}$C yr B.P. and ended prior to ~10,400 $^{14}$C yr B.P. That Lake Bonneville was high enough to support fish until 11,200 $^{14}$C yr B.P. is in conflict with chronologies that suggest that a near-desiccation of the lake occurred between 13,000 and 12,200 $^{14}$C yr B.P.

The $^{87}$Sr/$^{86}$Sr ratios from the stratum I fish suggest they were derived from a shallow-elevation lake (or lakes) near the Gilbert shoreline, and the data on size and relative taxonomic abundances suggest the fauna resulted from multiple die-offs which occurred when the lake dipped below this level. These findings can be interpreted in two ways.

First, the die-offs may have happened at widely separated times—initially at the end of the post-Provo regression and again after the lake regressed from a Younger Dryas age Gilbert-level lake (e.g., Oviatt *et al.,* 1992). Second, the stratum I fauna may have resulted from die-offs during short-term oscillations associated with a post-Provo regression. Recent data from sediment stratigraphy suggest there may not have been a transgression of Lake Bonneville to the Gilbert level

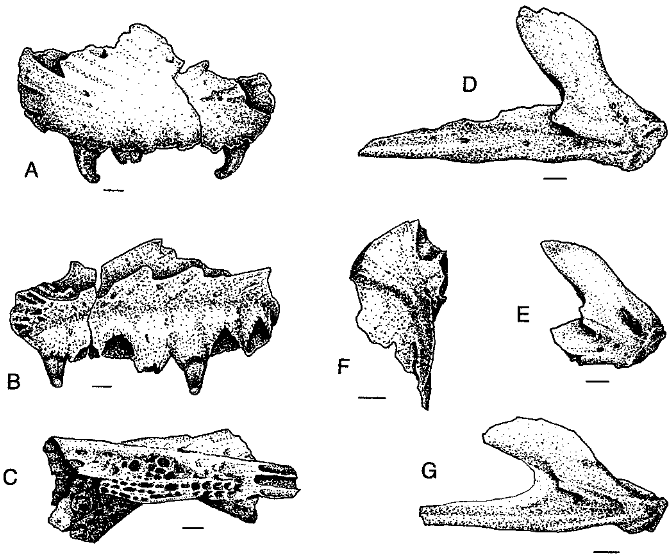

**FIG. 5.** Selected diagnostic salmonid elements from Homestead Cave: (A) lateral view of right premaxilla of cf. *Salvelinus confluentus,* (B) mesial view of right premaxilla of cf. *Salvelinus confluentus* (same specimen as A), (C) basibranchial of *Oncorhynchus clarki,* (D) left dentary of *Prosopium spilonotus,* (E) left dentary of *Prosopium abyssicola,* (F) left hyomandibular of *Prosopium gemmifer,* (G) left dentary of *Prosopium gemmifer.* Scale bar denotes 1 mm.

## TABLE 1
## Radiocarbon and Calibrated Ages from Homestead Cave

| Stratum | Age ($^{14}$C yr B.P.) | Age (cal yr B.P.)[a] | Lab. no. | Material |
|---|---|---|---|---|
| XVII | 1020 ± 40 | 925–961 | Beta 101877 | 30 g artiodactyl pellets |
| XVI | 1200 ± 50 | 1058–1216 | Beta 66940 | charcoal |
| XIV | 2850 ± 50 | 2873–3056 | Beta 103692 | 30 g artiodactyl pellets |
| XIII | 3480 ± 40 | 3689–3328 | Beta 101878 | 30 g artiodactyl pellets |
| XII | 3400 ± 60 | 3572–3695 | Beta 63179 | wood/charcoal |
| X | 5330 ± 65 | 5993–6266 | AA 14822 | 1 artiodactyl pellet |
| VII | 6160 ± 85 | 6906–7208 | AA 14824 | 1 artiodactyl pellet |
| VII | 6185 ± 105 | 6908–7248 | AA 14825 | 1 artiodactyl pellet |
| VI | 7120 ± 70 | 7865–8003 | AA 14826 | 1 artiodactyl pellet |
| V | 8230 ± 69 | 9033–9399 | AA 16810 | 1 artiodactyl pellet |
| IV | 8195 ± 85 | 9097–9397 | AA 14823 | 1 artiodactyl pellet |
| II | 8520 ± 80 | 9474–9547 | AA 14821 | 1 hackberry seed |
| II | 8790 ± 90 | 9808–10,146 | AA 14820 | 1 hackberry seed |
| II | 8830 ± 240 | 9544–10,221 | Beta 63438 | hackberry seeds |
| Ib (upper 5 cm) | 10,160 ± 85 | 11,706–12,105 | AA 14819 | 1 rodent pellet |
| Ib (upper 5 cm) | 10,350 ± 80 | 11,948–12,600 | AA 14818 | 1 rodent pellet |
| I | 10,910 ± 60 | 12,878–13,005 | Beta 72205 | bone collagen (*Marmota*) |
| Ia (lower 5 cm) | 11,065 ± 105 | 12,919–13,160 | AA 14817 | 2 rodent pellets |
| Ia (lower 5 cm) | 11,181 ± 85 | 13,018–13,187 | AA 16808 | 1 rodent pellet |
| Ia (lower 5 cm) | 11,263 ± 83 | 13,142–13,397 | AA 16809 | 1 rodent pellet |
| Ia (lower 5 cm) | 11,270 ± 135 | 13,039–13,431 | AA 14816 | 1 rodent pellet |

[a] At one standard deviation; calibrations based on data of Stuiver *et al.* (1998).

## TABLE 2
## Numbers of Identified Fish Specimens per Taxon by Stratum, Homestead Cave[a]

| | Stratum | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Taxon | I | Ia | Ib | I–II | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | XIII | XIV | XV | XVI | XVII | XVIII | Total |
| Salmoninae | 701 | 258 | 23 | — | 21 | 2 | 6 | 1 | 2 | 1 | — | 1 | — | — | 2 | 1 | 1 | — | 1 | — | 1 | 1022 |
| cf. *Salvelinus confluentus* | 1 | 0 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 1 |
| *Oncorhynchus* cf. *clarki* | 40 | 20 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 60 |
| *Oncorhynchus clarki* | 1 | 1 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 2 |
| *Prosopium* sp. | 945 | 5944 | 449 | — | 111 | 19 | 32 | — | 10 | 6 | 3 | 5 | 2 | 2 | — | 1 | 4 | — | — | 2 | 1 | 7536 |
| *Prosopium* cf. *spilonotus* | 79 | 5 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 84 |
| *Prosopium spilonotus* | 27 | 10 | 3 | — | 1 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 41 |
| *P. spilonotus/abyssicola* | 93 | 87 | 2 | — | 14 | — | 1 | — | — | — | — | — | — | — | 1 | — | — | — | — | — | — | 198 |
| *Prosopium abyssicola* | 2 | 6 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 8 |
| *Prosopium gemmifer* | 225 | 499 | 37 | — | 15 | 1 | — | — | — | 1 | — | — | — | — | — | — | — | — | — | — | — | 778 |
| Cypriniformes | 1167 | 471 | 58 | — | 44 | 10 | 28 | 4 | 19 | 10 | 8 | 22 | 13 | 45 | 224 | 48 | 23 | 1 | 7 | 38 | 5 | 2245 |
| Cyprinidae | 34 | 35 | 3 | — | 3 | 3 | 5 | — | 1 | 1 | — | 1 | — | 2 | 14 | 4 | 2 | — | — | 12 | — | 120 |
| *Gila atraria* | 443 | 191 | 26 | — | 12 | 7 | 17 | 1 | 13 | 10 | 3 | 14 | 6 | 13 | 59 | 40 | 17 | 2 | 20 | 63 | 1 | 958 |
| *Richardsonius balteatus* | — | — | — | 1 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 1 |
| *Catostomus* sp. | 900 | 299 | 24 | — | 19 | 4 | 20 | 2 | 7 | 6 | 7 | 5 | 2 | 3 | 25 | 6 | 9 | 2 | 1 | 2 | — | 1343 |
| *Catostomus ardens* | 134 | 22 | 7 | — | 2 | — | 4 | — | 1 | 1 | — | 1 | — | — | 5 | 1 | 1 | — | — | — | — | 179 |
| *Catostomus discobolus* | — | — | — | — | — | — | — | — | 1 | — | — | 3 | 1 | — | — | — | — | — | — | — | — | 5 |
| Cottus sp. | 53 | 178 | 9 | — | 13 | 5 | 1 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 259 |
| *Cottus* cf. *bairdi* | 0 | 1 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 1 |
| *Cottus bairdi* | 2 | 4 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 6 |
| *Cottus extensus/echinatus* | 3 | 9 | — | — | 2 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 14 |
| *Cottus extensus* | 0 | 5 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 5 |
| Total | 4850 | 8045 | 641 | 1 | 257 | 51 | 114 | 8 | 54 | 36 | 21 | 52 | 24 | 65 | 330 | 101 | 57 | 5 | 29 | 117 | 8 | 14,866 |

[a] Specimens identified are from the >6.4-mm and >3.2-mm sample fractions from Homestead Cave; nomenclature follows Robins *et al.* (1991). The osteological criteria used to identify these specimens are discussed elsewhere (Broughton, 2000a).

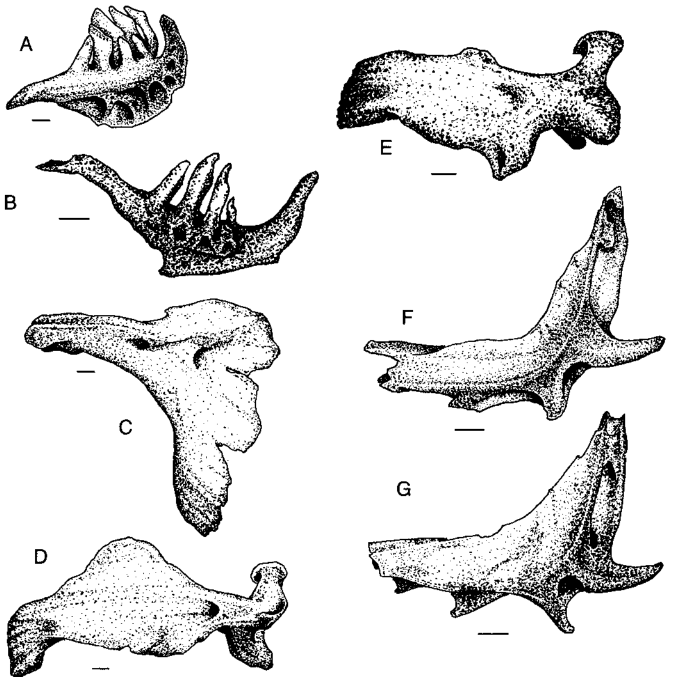

**FIG. 6.** Selected diagnostic cyprinid, catostomid, and cottid elements from Homestead Cave: (A) left pharyngeal of *Gila atraria,* (B) right pharyngeal of *Richardsonius balteatus,* (C) left dentary of *Catostomus ardens,* (D) right maxilla of *Catostomus ardens,* (E) right maxilla of *Catostomus discobolus,* (F) left preopercle of *Cottus bairdi,* (G) left preopercle of *Cottus extensus.* Scale bar denotes 1 mm.

during the Younger Dryas. Rather, the lake may have last been at that elevation during the post-Provo regression prior to ~11,500 $^{14}$C yr B.P. (Zachary and Oviatt, 1999).

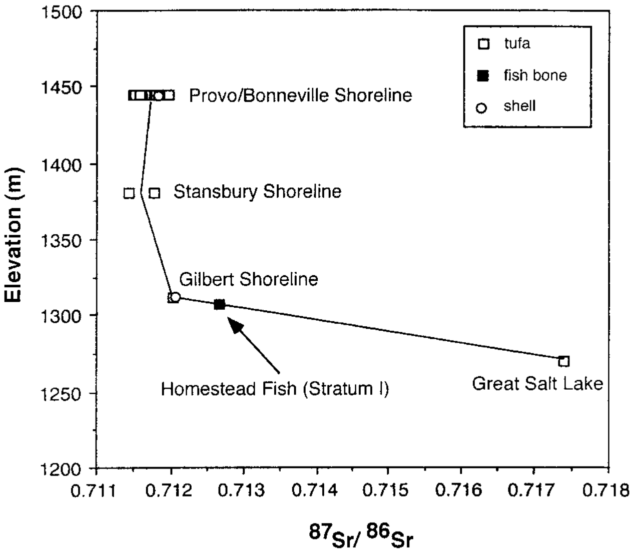

**FIG. 7.** The $^{87}$Sr/$^{86}$Sr ratios for materials derived from Lake Bonneville shorelines and the Homestead Cave fishes. The procedures used to pretreat carbonates and apatites follow Bouchard *et al.* (1998) and Schmitz *et al.* (1991), respectively.

**TABLE 3**

**Vertebral Widths (mm) of the Stratum I Cypriniformes**

| Stratum | *N* | Mean[a] | Range | Standard deviation |
|---|---|---|---|---|
| Ia | 365 | 4.40 | 1.26–9.20 | 1.46 |
| Ib | 56 | 4.02 | 1.74–7.62 | 1.38 |

[a] By comparison, the mean vertebral widths of a modern 450-mm SL *Catostomus ardens* and a 202-mm SL *C. discobolus* are 8.76 and 2.84 mm, respectively.

## *Lake-Level Fluctuations of Great Salt Lake*

Although *G. atraria* has never inhabited Great Salt Lake historically, this species is tolerant of moderate salinity levels and warm water temperatures and is the only member of the Lake Bonneville fauna that now occupies low-elevation creeks, springs, and marshes of the northern Bonneville basin. However, based on genetic analyses of modern populations of *G. atraria* in the region, Rosenfeld (1991, p. 89) suggested that during wetter periods of the Holocene, Great Salt Lake may have become sufficiently diluted to support this species. Even if *G. atraria* could not have invaded Great Salt Lake during

**TABLE 4**

**Numbers of Identified Specimens for Salinity and Temperature Tolerant and Intolerant Fish Taxa from Stratum I, Homestead Cave[a,b]**

| | Stratum | | Stratum | |
|---|---|---|---|---|
| Taxon | Ia | % | Ib | % |
| Salinity tolerant | | | | |
| *Gila atraria* | 226 | 3.0 | 29 | 4.9 |
| Salmoninae | 279 | 3.7 | 23 | 3.9 |
| Total | 505 | 6.7 | 52 | 8.9 |
| Salinity intolerant | | | | |
| *Prosopium* | 6551 | 86.5 | 491 | 84.2 |
| *Catostomus* | 321 | 4.2 | 31 | 5.3 |
| *Cottus* | 197 | 2.6 | 9 | 1.5 |
| Total | 7069 | 93.3 | 531 | 91.1 |
| Temperature tolerant | | | | |
| *Gila atraria* | 226 | 3 | 29 | 5.0 |
| *Catostomus* | 321 | 4.2 | 31 | 5.3 |
| Total | 547 | 7.2 | 60 | 10.3 |
| Temperature intolerant | | | | |
| *Prosopium* | 6551 | 86.5 | 491 | 84.2 |
| Salmoninae | 279 | 3.7 | 23 | 4.0 |
| *Cottus* | 197 | 2.6 | 9 | 1.5 |
| Total | 7027 | 92.8 | 523 | 89.7 |

[a] Salinity and temperature tolerances are derived from Westenfelder *et al.* (1988), Sigler and Sigler (1996), Wydoski and Whitney (1979, p. 41), Vigg and Koch (1980), and Jobling (1981).

[b] We assume here that the specimens identified as "Salmoninae" represent *O. clarki* because this species was the only salmonine present in the materials of stratum Ia and Ib. Similarly, we assume the materials identified as *Catostomus* represent *C. ardens.*

**TABLE 5**
**Numbers of Identified Mammal and Fish Specimens by Stratum, Homestead Cave**

| Stratum | Mammals[a] | Fish | % fish |
|---|---|---|---|
| XVIII | 1047 | 8 | 0.08 |
| XVII | 15,548 | 117 | 0.08 |
| XVI | 6296 | 29 | 0.05 |
| XV | — | 5 | — |
| XIV | — | 57 | — |
| XIII | — | 101 | — |
| XII | 22,860 | 330 | 1.42 |
| XI | 10,096 | 65 | 0.06 |
| X | 6601 | 24 | 0.04 |
| IX | 22,088 | 52 | 0.02 |
| VIII | 8289 | 21 | 0.03 |
| VII | 13,905 | 36 | 0.03 |
| VI | 24,330 | 54 | 0.02 |
| V | 5109 | 8 | 0.02 |
| IV | 26,615 | 114 | 0.04 |
| III | 2884 | 51 | 1.70 |
| II | 7855 | 257 | 3.17 |
| I[b] | 10.275 | 3702 | 26.49 |
| Total | 183,798 | 5031 | 2.66 |

[a] From Grayson, (2000). Mammal materials from stratum XIII through stratum XV were not identified.

[b] In stratum I, only the mammal specimens from provenience unit FS-63 were identified. To provide a valid comparison, the identified fish specimens from stratum I presented here are from that unit only.

wetter cycles, the extent of local freshwater marshes should have varied with regional moisture and the elevation of the lake. In any case, change in the Holocene abundance of *G. atraria* near the cave should be linked to higher elevations of Great Salt Lake.

Materials representing the Lake Bonneville fish fauna occur in extremely low frequencies above stratum I and likely owe their presence in those contexts to limited mixing. However, the *G. atraria* materials in these upper strata may be derived not only from limited mixing with stratum I but also from Holocene-aged scavenging by owls. If owls deposited a lot of *G. atraria* during Holocene transgression–regression cycles of Great Salt Lake, then major frequency peaks of *G. atraria* within the cave deposits should signal those cycles.

The absolute abundance of *G. atraria* has two main peaks in Holocene strata at the cave, first within stratum XII and second within stratum XVII (Fig. 8). According to limited core and shoreline data, the most notable Great Salt Lake highstand occurred between ~3000 and 2000 $^{14}$C yr B.P. when the lake appears to have transgressed to a highstand of 1287 m and flooded the Great Salt Lake Desert (Mehringer, 1985; McKenzie and Eberlie, 1987; Murchison, 1989). This highstand may be recorded by the substantial increase in *G. atraria* within stratum XII that yielded a radiocarbon age of 3400 $^{14}$C yr B.P. Although this age is ~400 $^{14}$C yr earlier than the beginning of the proposed Holocene maximum, the ages are uncertain and it is likely that the phenomena are related. The second spike in *G. atraria* occurs within stratum XVII, a context that yielded a radiocarbon age of 1020 $^{14}$C yr B.P. Although a highstand of Great Salt Lake after ~1000 $^{14}$C yr B.P. has been documented from shoreline data, those data suggest the lake reached only to an elevation of ~1283 m and did not flood the Great Salt Lake Desert (Murchison, 1989; Currey, 1990).

## SUMMARY

The fish materials from Homestead Cave are concentrated in the lowest stratum of the deposit and are represented by 11 freshwater species. The fish remains appear to have been accumulated by scavenging owls. The $^{87}$Sr/$^{86}$Sr values from the stratum I fish suggest they were derived from a low-elevation lake, near the elevation of the Gilbert shoreline. A significant decrease in the size of cypriniform vertebrae, documented across the two divisions of the stratum I deposits, suggests that the fauna resulted from a process involving multiple die-offs. Taxa tolerant of higher salinities and temperatures are more abundant in the upper division of stratum I than in the lower section of this deposit. The initial post-Provo die-off of the Lake Bonneville fish fauna occurred at ~11,200 $^{14}$C yr B.P., but the entire Bonneville fish fauna recolonized the lake as it oscillated near this position or rebounded with a Younger Dryas age transgression to the Gilbert level. Fish were gone from the lake by 10,400 $^{14}$C yr B.P. or possibly earlier. The persistence of a diverse, cool-water fish fauna in Lake Bonneville until an initial die-off at ~11,200 $^{14}$C yr B.P. conflicts with chronologies that posit a near-desiccation of the lake as early as 13,000 $^{14}$C yr B.P. Frequency peaks of *G. atraria* in the upper strata of the cave imply two late Holocene highstands

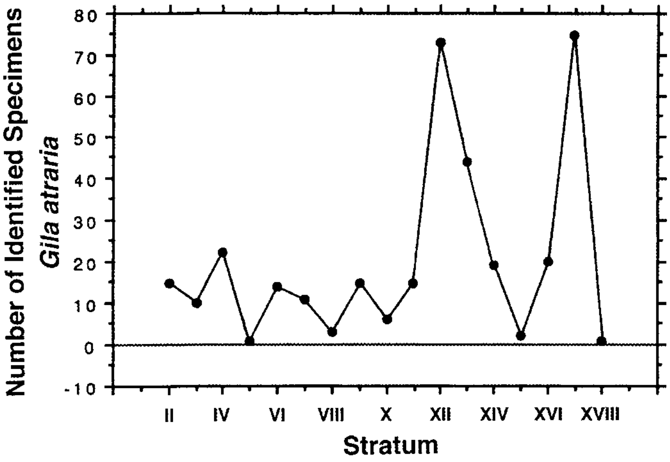

**FIG. 8.** Number of identified specimens of *Gila atraria* by stratum (exclusive of stratum I) at Homestead Cave. Specimens identified as "Cyprinidae" are included with *Gila atraria* because that species represents well over 99% of the identified cyprinids at Homestead Cave.

of the Great Salt Lake, one at ∼3400 $^{14}$C yr B.P. and the other at ∼1000 $^{14}$C yr B.P.

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