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CHANGES IN SALINE AND ALKALINE LAKE AVIFAUNAS IN WESTERN NORTH AMERICA IN THE PAST 150 YEARS

JOSEPH R. JEHL, JR.

Abstract. I use biological, historical and limnological data to consider how changes at some of the major saline and alkaline lakes in the western United States may have affected their ability to support breeding and migratory birds in the past 150 years. I emphasize hypersaline lakes (salinities >50‰), where the birdlife is dominated by a few species, principally California Gull, Wilson's Phalarope, Red-necked Phalarope, and Eared Grebe, that can exploit the abundant invertebrate prey resources. Of eight lakes treated in detail, two have been irretrievably lost, and the long-term survival of another is questionable. Major engineering modifications are planned or in effect at three others. Only two or three lakes seem likely to be able to support their current avifaunas well into the next century.

Key Words: Pyramid Lake, NV; Winnemucca Lake, NV; Carson Sink, NV; Great Salt Lake, UT; Lake Abert, OR; Mono Lake, CA; Owens Lake, CA; Salton Sea, CA; Eared Grebe; *Podiceps nigricollis*; Wilson's Phalarope; *Phalaropus tricolor*; Red-necked Phalarope; *P. lobatus*; California Gull; *Larus californicus*.

Scattered through the aridlands of the western United States and southwestern Canada, the saline and alkaline lakes of North America constitute an important but generally unappreciated resource for migratory birds (Behle 1958, Winkler 1977, Boula 1985, Jehl 1988 and references therein). They are often characterized by high rates of annual production, which provides the food resources for the migrants. Their fresh water input is seasonal, mostly deriving from winter precipitation that will evaporate during the following summer. The majority are shallow, and all but the largest undergo important annual and seasonal fluctuations in size and salinity. Indeed, lakes that have been productive for years can disappear in a short time. This means that their biota must either be physiologically flexible and able to withstand long periods of highly variable and sometimes harsh conditions, or, like birds, be opportunistic and able to disperse when conditions require (Jehl 1988).

Limnologists consider a lake to be saline when its salinity (or total dissolved solids) attains 3‰ (Hammer 1986). Biotic diversity varies inversely with concentration. Many bird species tolerate salinities up to 10–12‰, then drop out. Concentrations of ≈15‰ are a barrier to reproduction in waterfowl (e.g., Moorman et al. 1991). Most fish cease to breed at 40–45‰, and at 50–60‰, in the absence of these and other predators (e.g., corixids, copepods) the invertebrate fauna becomes a biculture of brine shrimp (*Artemia* sp.) and brine flies (*Ephydra* sp.). Those invertebrates can become an almost unlimited food resource for the few bird species that can exploit tiny prey without ingesting the noxious water (e.g., Mahoney and Jehl 1985). Prominent avian species in or around hypersaline lakes (>50‰) include American Avocets (*Recurvirostra americana*), Black-necked Stilts (*Himantopus himantopus*), Snowy Plovers (*Charadrius alexandrinus*), and California Gulls (*Larus californicus*), which are common breeders, and the migrant Wilson's (*Phalaropus tricolor*) and Red-necked (*P. lobatus*) phalaropes and Eared Grebes (*Podiceps nigricollis*), which seem inured to almost any level of salinity, so long as prey persist.

In this paper I supplement the meager biological data with limnological and historical records to consider how conditions at some of the major Great Basin lakes, especially those with hypersaline environments, may have affected their ability to support birdlife in the historical period (1840–present). Information on the geological histories of many of these lakes and basins can be found in Hubbs and Miller (1948).

FIGURE 1. Aerial view of Pyramid Lake, NV. The dry, white alkali basin to the east is the remains of Winnemucca Lake. Both lakes were fed by the Truckee River, which enters from the south and bifurcates before entering Pyramid Lake. Pyramid Lake received water first, because of its lower elevation, and then spilled in Winnemucca Lake, which became "extinct" in the late 1930s.

PYRAMID LAKE, NEVADA

Pyramid Lake, discovered by Capt. John Charles Frémont in 1844, is a meager remnant of Pleistocene Lake Lahontan, which once covered 22,000 km^2 of western Nevada to a maximum depth of 157 m. Even so, Pyramid remains the largest (444 km^2), deepest (103 m), and limnologically perhaps the most stable of the major saline lakes in North America (Hammer 1986; Fig. 1). It is slightly saline ($\approx$5‰) and sustains amphipods, fish, (including the endangered cui-ui, [*Chamistes cujus*]), and other potential prey for aquatic birds. In the prehistoric period it was a major site for aboriginal people, who made extensive use of waterfowl in migration (Knack and Stewart 1984).

Like other Great Basin lakes, Pyramid reached peak elevations in the late 19th century, but then began to decline, owing to the diversion of the Truckee River and the completion of the Newlands Irrigation Project (1903); between 1890 and 1980 it dropped by 21 m (Fig. 2). This probably had little effect on the birdlife, because the salinity was low and changes were slight.

This lake's most important avian resources are the colonial birds breeding on Anaho Island National Wildlife Refuge (established in 1913). Baseline historical data come from periods when the lake was relatively high and include reports by Robert Ridgway (1877) and E. R. Hall (1924). The latter spent the summer of 1924 there, noting 14 species of waterbirds, of which only the White Pelican (*Pelecanus erythrorhynchos*), California Gull, and Double-crested Cormorant (*Phalacrocorax auritus*) were common. Through most of this century the pelican colony has been among the largest in the United States, typically holding 3000–

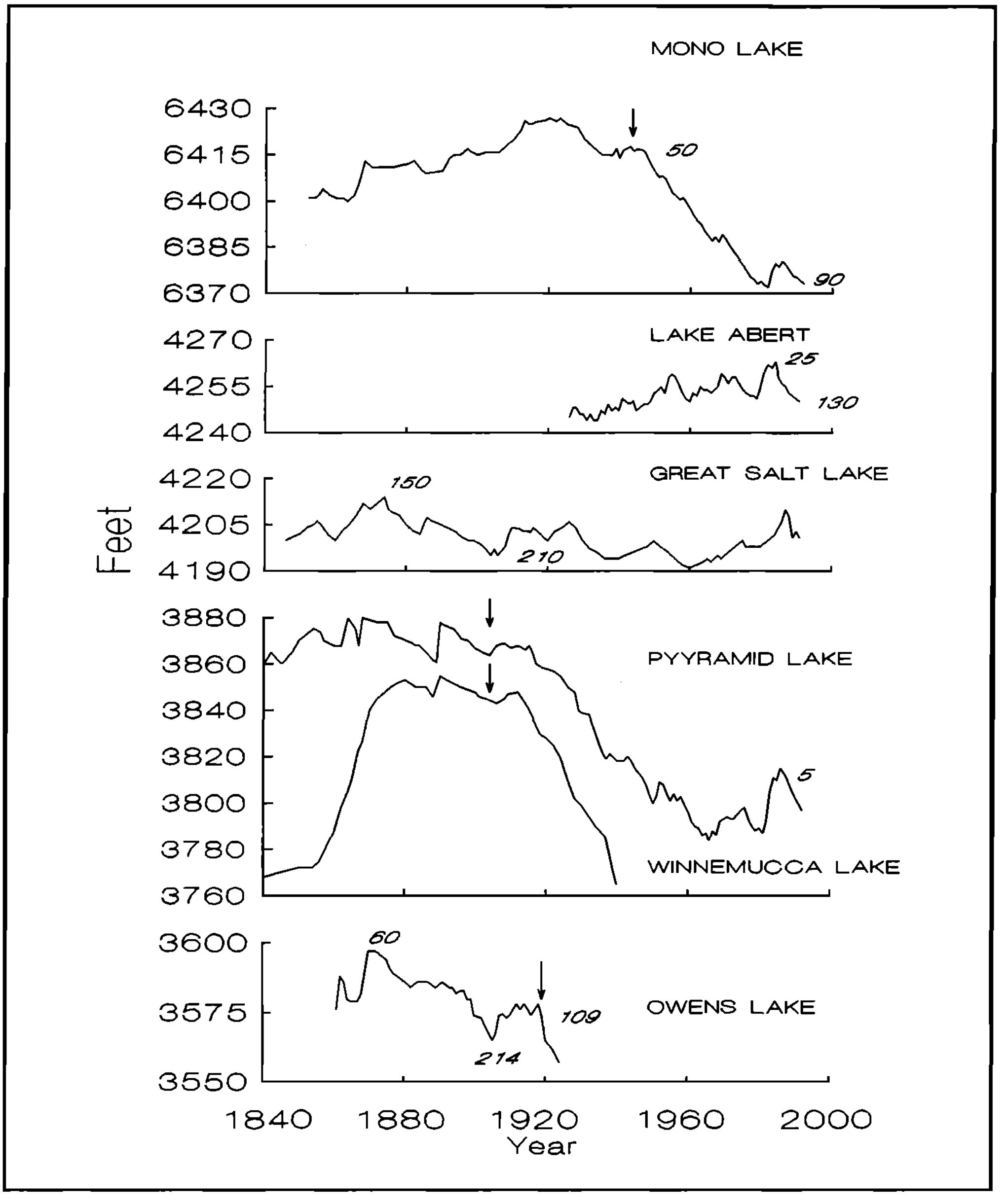

FIGURE 2. Changes in the surface elevations of some major saline lakes in western North America. Approximate salinities are indicated in italics. Arrows indicate the start of diversion projects.

5000 nests (A. Janik, pers. comm.; Marshall and Giles 1953). Colony size (range—50 pairs in 1988 to 10,700 pairs in 1986) and productivity are influenced by foraging conditions in the Lahontan Basin, 96 km to the south. In good years productivity averages nearly 1 chick/pair, but in the recent drought (e.g., 1988–1992) virtually no young fledged.

Gull populations have also fluctuated, but seem to have shown little overall change. They were exploited by native people and miners before the refuge was created (Hall 1924), but from 1986–1992 counts have averaged about 2600 pairs (maximum 4240 in 1992; R. Anglin, pers. comm.), which is about the size of the colony described by

Ridgway in 1877 (Yochem et al. 1991). Cormorants are likely to have increased after the refuge was created. Hall (1924) reported "several hundred and perhaps a thousand" adult birds; this can be compared to 1330 nests in 1951, and an average of 1700 nests (maximum 5400) from 1986–1992 (R. Anglin, pers. comm.).

At one time the potential landbridging of Anaho Island was a concern (Marshall and Giles 1953), but resolution of the water rights of native peoples at Pyramid Lake, coupled with regulations to preserve the cui-ui, has resulted in increased inflow, making it likely that the integrity of the island and the colonies will be maintained.

WINNEMUCCA LAKE, NEVADA

Winnemucca Lake, 8 km to the east of Pyramid Lake, was not mentioned by Frémont, and may have barely existed at that time (Hardman and Venstrom 1941), owing to a long dry spell. It first appeared on maps as Mud Lake, a very small body of water, in 1850. With the return of wet conditions in 1859–1860 lakes throughout the Great Basin began to fill, and by 1882–1889 Winnemucca was 42 km long, 6 km wide, and 26 m deep. A subsequent dry period and the diversion of the Truckee River (1903) led to the lake's terminal decline.

The Winnemucca basin is steep-sided and lacks fringing mudflats or marshes. Archaeological evidence suggests that it was probably more productive and attractive to native people at relatively low stands, when marshes at the southern end attracted numerous migrating waterfowl (Hattori 1982). The wildlife values were recognized in 1936, when President Roosevelt created the Winnemucca Lake National Wildlife Refuge, but too late. The President's signature had barely dried when, in 1938, the lake followed suit. Subsequently, even under the best spring runoff conditions, it was never more than an ephemeral sheet of water. With no possibility of obtaining water, the Fish and Wildlife Service abandoned the refuge in 1962.

FIGURE 3. The Swesey family of Nevada boating on (ostensibly) Lake Winnemucca about 1911–1914. Courtesy of Special Collections, University of Nevada, Reno.

Little information about wildlife populations has been preserved. In June 1889, Keeler (1889) compiled a list of 51 bird species, which included all of the expected waterbirds, none in notable quantity. His report is likely incomplete because the lake was high and he would have needed a boat to visit open-water habitats (Fig. 3). However, he did note that a grebe (probably *Aechmophorus* sp., though listed as *Colymbus holboellii*) was very common, and that Eared Grebes were fairly common in the slough. Also common were California Gulls and White Pelicans, visitors from Pyramid Lake.

Because Winnemucca Lake did not have its own source of water, but was fed by the Truckee River via overflow from Pyramid Lake (Fig. 1), it was subject to large limnological changes. At its high point it was alkaline and brackish; yet, at the low levels of the 1920s it was still sufficiently fresh to accommodate a commercial fishery (Hattori 1982). Accordingly, it could not have maintained significant brine fly or brine shrimp populations or been an important concentration point for bird species that require more saline habitats.

THE CARSON SINK AREA, NEVADA

Many pioneers through the Great Basin followed the Humboldt River southwesterly for 500 km across Nevada, before it ended in the Humboldt Sink. Adjacent to this in the south they found the Carson Sink, which captures the outfall of the Carson River as it enters from the west.

The Carson Sink once consisted of 190,000 acres of wetlands (R. Anglin, pers. comm.), and held enormous concentrations of waterfowl (Thompson 1986). The completion of the Newlands Project diverted additional water into the area, which wound up being used by industry, homes, and farms, so that only agricultural runoff of questionable quality was left for the marshes. Even so, enough drizzled through that 23,000 acres became the Stillwater National Wildlife Refuge and Game Management Area in 1948.

The existence of these Lahontan Valley wetlands played a mitigating role in the abandonment of the Winnemucca Lake refuge. In 1960 the Fish and Wildlife Service considered that the "relatively new Stillwater Wildlife Management Area . . . appears to adequately provide for the segment of the Pacific Flyway waterfowl which pass through the area." Presciently, it added that Stillwater lacked a secure water supply and that its adequacy "to serve waterfowl needs may not always be thus" (USFWS 1960).

Stillwater, like other interior basin wetlands, is an oasis for transient waterfowl that winter in the Central Valley of California (see also Banks and Springer 1994). In 1988, for example, it attracted 400,000 ducks, including 25% of the Pacific Flyway population of Canvasbacks (*Aythya valisneria*). At other times it has been a major breeding area for Redheads (*Aythya americana*), White-faced Ibis (*Plegadis chihi*), and Canada Geese (*Branta canadensis*). In spring and fall migrating Avocets, Black-necked Stilts, Wilson's Phalaropes, and Long-billed Dowitchers (*Limnodromus scolopaceus*) can occur by the tens of thousands.

The problem of a secure water supply remains. The wetlands still fluctuate with rainfall and runoff, but unpredictably and unreliably. In 1983–1984 they were flooded and fresh, encompassing >100,000 acres. But the drought returned—and with it high salinity—and the marshes dried out.

The value of the Carson Sink was finally acknowledged in 1988, when funds to purchase water rights and marginal agricultural land in the Fallon area were made available by Congress and local bond issues. Unfortunately, the drought persisted, undermining this artificial, economic "solution" to a problem caused by too many people. After providing water to Reno, farms near Fallon, and Pyramid Lake (partly to sustain a *single* fish species under the uncompromising mandate of the Endangered Species Act), there was nothing left in the Truckee to support *large and diverse populations* of wetland-requiring birds! (In this case, application of the ESA could result in the creation of additional endangered species or populations). In 1992 only 550 acres of marsh remained, and Stillwater, like its precursor Winnemucca Lake, could no longer be managed for the resources it was established to preserve (R. Anglin, pers. comm.). The wet winter of 1992–1993 barely ameliorated the situation, and Stillwater's long term ability to support breeding and migratory birds is problematical.

GREAT SALT LAKE, UTAH

Wildlife, specifically beaver pelts, was central to the exploration of Great Salt Lake in the 1820s. Birds, attracted by uncountable populations of alkali flies and brine shrimp, were also noted by early explorers. Ogden reported thousands of gulls in Cache Valley in 1825 (evidently California Gulls, which should then have been called "Utah Gulls", but the species was not described until 1854). Frémont in 1843–1844 described "enormous concentrations of waterfowl" and "flocks of screaming plover" at the deltas of the Bear and Weber rivers, and Stansbury in 1850 discovered the California Gull colonies that have so greatly influenced local lore (see Behle 1990 for a masterly treatment of the history of Utah ornithology).

As a salt lake, Great Salt Lake is relatively young, having attained its current size and conditions about 11,000 years BP (Arnow 1984). Its precursor was Pleistocene Lake Bonneville, a freshwater lake that covered 52,000 km^2 of Utah, Nevada, and Idaho to a maximum depth of 1600 m. In the brief historical period Great Salt Lake has undergone large fluctuations in size (from 2600–6500 km^2) and salinity (150–210‰, prior to 1960; Arnow 1984). The changes, which can be rapid, affect birdlife by landbridging or drowning nesting islets, affecting food supply, and creating or eliminating freshwater habitats. Between September 1982 and July 1984, a 3 m rise inundated and salt-burned major waterfowl nesting areas at Bear River National Wildlife Refuge, causing its closure for several years.

Behle (1958) reviewed changes in the avifauna and noted the expansion and shifting of the gull colonies. From the early 1930s through the 1980s the population showed little change at 75,000–80,000 birds (Paul et al. 1990:301), then jumped to 134,000–156,000 in 1990–1993 (fide Utah Division of Wildlife Resources). Behle (1958) also reported decreases in White Pelicans, herons, and Double-crested Cormorants, but these seem to have been short-term responses to fluctuating lake levels and have been reversed (Utah Division of Wildlife Resources). More recent studies have established Great Salt Lake as North America's largest fall staging area for Wilson's Phalaropes and the second largest for Eared Grebes (Jehl 1988). Up to one million Red-necked Phalaropes have been alleged in fall (Kingery 1982), but recent estimates have been much lower (100,000–240,000; D. Paul, pers. comm.). All estimates, however, need reevaluation, because (like those for most nonbreeding birds at this immense lake) they are based on extrapolation. Until thorough aerial surveys can be made over open-water habitats in late August, when Red-necked Phalaropes peak, the true abundance of this species will remain unknown. White Pelican colonies on Gunnison Island sometimes surpass those at Pyramid Lake (maximum 9000 pairs; D. Paul, pers. comm.). The basin also holds the world's largest breeding assemblage of California Gulls, Snowy Plovers (Paton *in* Page and Gill 1994) and White-faced Ibis.

The lake today is a far different place from that seen by Ogden in 1825, or even by Behle in 1958. It is the most modified—and most diversified—of our salt lakes. Wildlife habitat along the east and south shores has been lost to industry and agriculture, although this has been tempered by the creation of fresh and brackish impoundments of wetlands for state and federal refuges and private duck clubs. The extensive dike systems of commercial salt works contribute nesting areas for gulls and waterfowl. The most profound change limnologically has resulted from the construction of a trans-lake causeway for the railroad in 1957–1959. This separated the lake into a highly saturated (≈250‰) and often sterile North Arm, and a more productive South Arm (100–120‰; Butts 1980). (Note that conditions within these two broad areas are rarely uniform. Subareas with different salinity regimes in the South Arm include the Bear River marshes, Farmington Bay, Ogden Bay, and Stansbury Bay). When the lake underwent a major rise in 1984, salinity in the South Arm dropped to ≈50‰ and the invertebrate fauna changed from one dominated by brine shrimp to an assemblage in which brine shrimp were made rare by corixid predation (Wurtsbaugh and Smith-Berry 1990). The North Arm, which had been sterile, was quickly repopulated by shrimp (Fig. 4), and Wilson's Phalaropes and Eared Grebes shifted out of the fresher areas and followed their prey north, not returning to the South Arm until salinity increased in 1988 (76‰).

If proposed today, the separation of Great Salt Lake into two halves, one of which was sterile, would likely be ridiculed as being environmentally damaging. Yet, the building of the causeway, which reduced salt loads in the South Arm, and other man-made

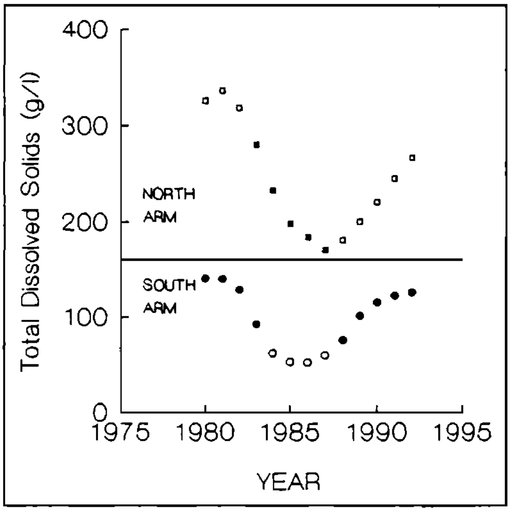

FIGURE 4. Changes in salinity and in the location of commercial brine shrimp harvesting activities (solid figures) in the North and South arms of Great Salt Lake, Utah. Brine shrimp are a major prey for aquatic species occupying hypersaline lakes.

modifications have enhanced habitat diversity, such that Great Salt Lake is ornithologically the most impressive salt lake on the continent. On the other hand, the biological justification of a current proposal to create a freshwater enclosure ("Davis Lake") within the lake—by impounding the flow of the Jordan River behind Antelope Island—is questionable. While this would create additional large areas of fresh or brackish water, it would also eliminate a major source of fresh water, and thus change salinity regimes in the South Arm. If diversions cause salinity to rise beyond the tolerance of the prey populations, as in the North Arm, the lake's habitat for halophilic species of invertebrates and birds would be effectively lost.

LAKE ABERT, OREGON

Lake Abert (Fig. 5), in south-central Oregon, is by far the state's largest salt lake. It was named by Frémont in 1843 for his boss, Colonel J. J. Abert, Chief of the U.S. Topographical Engineers (and father of J. W. Abert, the inspiration for the towhee's patronym; McKelvey 1955). At its high point (in 1984) it covered 155 km^2, was 5 m deep, and had a salinity ≈25‰. Its shallow basin results in highly variable limnological conditions, and in some years (most recently 1937) the lake has been dry.

In the past decade, at least, the lake's abundant although variable populations of brine flies and brine shrimp (commercial harvest ≈20 tons in 1990) have attracted bird populations that have sometimes been impressive. Except for perhaps 1000 pairs of American Avocets and 100 pairs of Snowy Plovers, which occupy alkali flats, few birds breed (Keister 1992). Yet it attracts thousands of migrating shorebirds (avocets, stilts, peep), gulls, and waterfowl (Boula 1985); it is a major staging and molting area for southbound Wilson's Phalaropes in July–August (Fig. 6), and has sometimes held the second-largest concentration of that species in the U.S. (150,00 in 1981). Up to 15,000 Eared Grebes molt and stage there into September (Boula 1985, Jehl 1988). Several thousand Ruddy Ducks (*Oxyura jamaicensis*) and Shovelers (*Anas clypeata*) are sometimes present (Boula 1985) and may use it as the destination for a molt migration (Jehl, unpubl.).

Lake Abert is fed by the Chewaucan River, which "before 1915 flowed through Chewaucan Marsh . . . . After the marsh was drained, between 1884 and 1915, some of the water was used to irrigate the newly-formed agricultural land" (Keister 1992). In 1993 plans were approved to dam the river to create a freshwater marsh, as well as to impound 8 km^2 on the west side for mineral extraction. While the impact on bird populations may not be significant (Keister 1992), such an action would inevitably lead to an increase in mean salinity and more frequent intervals of desiccation.

For stable bird populations it might seem desirable, then, to manage the lake for higher levels. However, periodic drying is required to maintain the viability of shallow lakes (Van Denburgh 1975), because this precipitates salts, which can be removed by deflation. While desiccation can cause short-

FIGURE 5. Lake Abert, Oregon.

term challenges for the biota (Keister 1992), the alternative is a build-up of salts to concentrations that no longer support prey populations.

Over the long term, Keister (1992) concluded that the hydrology of Lake Abert was probably close to that found before the advent of modern agriculture. By extension, it would seem that the bird populations have not changed much because of local anthropogenic actions, but the paucity of historical data precludes any firm conclusions.

MONO LAKE, CALIFORNIA

Mono Lake, the fourth largest (178 km^2) saline lake in North America, is also probably the oldest and most reliable habitat for hypersaline lake birds, as it has been in existence for 750,000 years and saline for at least 100,000 years (NAS 1987, Newton 1991). It was discovered in 1852, and for most of the historical period salinity has approximated 45–60‰ (NAS 1987). Substantial water has been diverted from streams feeding Mono Lake for most of this century. After the City of Los Angeles began to divert feeder streams in 1940 lake level began to decline and by 1982 salinity approximated 90‰. Increased salinity, per se, probably had little effect on bird populations, as the salinity was already at or above the threshold for most invertebrates, other than brine shrimp and brine flies (see also Wurtsbaugh and Smith-Berry 1990 for changes in Great Salt Lake). However, physical changes associated with changing water levels were significant. At high stands there were freshwater marshes, which attracted abundant and diverse migrating waterfowl said to number in the hundreds of thousands. Today, annual waterfowl populations approximate 15,000 and are dominated by Ruddy Ducks (which use the area for a molt migration; Jehl, unpubl.), Shovelers, and Green-winged Teal (*Anas carolinensis*).

FIGURE 6. Adult female Wilson's Phalaropes staging at Abert Lake, Oregon in early July. Other major concentration points are Mono Lake, Great Salt Lake, and, in some years, the Carson Sink.

The world's second-largest assemblage of California Gulls breeds on a series of islands in Mono Lake. First reported by Wm. Brewer in 1863, this colony has become symbolic of environmental values in efforts to stop water diversion (e.g., NAS 1987). While many hypersaline lake birds probably have a long history at Mono Lake, the gulls' occurrence as nesters must be relatively recent, because the oldest island dates only to 1700 BP (S. Stine, pers. comm.). The first quantitative estimates of colony size are 2000–3000 birds in 1916–1919 (Jehl et al. 1984). Now (1992), in spite of a half-century of water diversions, there are 65,000. Court rulings requiring that the lake be maintained high enough to insure the presence of some islands insures that the persistence of a large gull colony is no longer in doubt.

Mono Lake is the continent's (world's?) largest molting and staging area for Eared Grebes, with fall populations thought to approximate 750,000–1,000,000 birds. We know that numbers were sufficiently large to attract commercial hunters in the 19th century (Denton 1949). Whether they matched current numbers is unknowable, but perhaps unlikely for two reasons: 1) the destruction for agriculture of wetland breeding areas in the interior of the continent; and 2) the presence of a similar site nearby, Owens Lake, which held immense numbers, at least in some years. Wilson's Phalaropes also use Mono Lake as a molting and staging area before migrating to South America, and thousands of Red-necked Phalaropes pass through in the fall. In the period 1980–1993 peak numbers of both of these migratory species were variable, owing to conditions elsewhere in the range. In the early 1980s, for example, peak numbers of Wilson's averaged 50,000–70,000 individuals, making Mono second to Great Salt Lake as a staging area; later in that decade numbers dropped, concurrent with a major drought in the western and central U.S. and Canada. The historical record is too vague to determine changes in status, except to indicate that both species have long been present (Jehl 1986, 1988).

OWENS LAKE, CALIFORNIA

Owens Lake, which like Mono Lake lies in the rainshadow of the Sierra Nevada, has been hypersaline for the last 6000 years (Newton 1991). It was discovered by Joseph Reddiford Walker in 1834, and named by Frémont in 1834 for Richard Owens, a member of his expedition. In 1864 Brewer (1966) called it "the color of coffee . . . nearly a saturated solution of salt and alkali." After the wet winter of 1867–1868 it deepened by 3 m (9 m by 1872), yet remained hypersaline (68‰). In 1872 it covered 285 km² and was home to an 85-foot steamboat that carried silver bullion across the lake for shipment by mule train to Los Angeles.

Some of the Owens River was diverted for agriculture in the late 1800s, but this was only a minor cause of the lake's decline to 1905, when "bicarbonate of soda precipitates during the winter months without evaporation" (Newton 1991). The lake must have been intermittently sterile then (214‰). It eventually rose about 3 m but in 1917 the Owens River was diverted for Los Angeles and the lake died (Fig. 7).

Scanty but critical data establish the lake's attractiveness to birdlife before diversions. Dawson (1922:50) wrote that he had been "lured to this section [in 1919] by extravagant accounts of extensive swamps where ducks bred by thousands; but what we found, instead, was a few decadent sloughs, which were being sucked dry by the feeders of the great Los Angeles aqueduct." Kahrl (1982: 35) quotes an early settler that "the lake was once 'alive with wild fowl, from the swift flying Teel to the honker goose . . . . Ducks were by the square mile, millions of them. When they rose in flight, the roar of their wings . . . could be heard on the mountaintop at Cerro Gordo, ten miles away . . . .'" While estimates of bird numbers and sound transmission are easily exaggerated (the loudest thunder clap can be heard only six miles away; F. Awbrey, pers. comm.), the abundance of waterfowl (most probably the salt-tolerant Ruddy Ducks and Shovelers) seems evident.

The lake's enormous alkali fly populations, which were also used as food by Paiute Indians, were the major and perhaps sole attraction for phalaropes and grebes. In late July or early August 1859, Davidson (Wilkie and Lawton 1976:24) reported "whole navies of Aquatic birds . . . about the size of jack snipe, have a sharp, straight bill, and the Indians represent them as half-webbed and having a small fleshy paddle projecting from the outer toe." While this description could loosely apply to either the Wilson's or Red-necked phalaropes, it may pertain mainly to Wilson's, which migrate earlier than the Red-necked (Jehl 1988).

The lake's use by molting and staging Eared Grebes was established by the local press (also Fisher 1893), which reported "legions upon legions of a so-called 'duck . . .'" which "have no real wings or feathers and consequently cannot fly . . ." (*Inyo Register*, 4 April 1882). Two years later the *Inyo Independent* (20 June 1874), was still bemused, but entirely accurate in its observations:

"*A query for Ornithologists*

> On Owens Lake there are at all seasons of the year myriads of small waterfowl, considerably smaller than the common diver for which they are often taken by casual observers. "The bird is of the diver species doubtless, since it is a good diver and swimmer, but in other physical abilities it is different from any other we have ever heard of. If what we are told about it is true . . . it can neither walk nor fly. Thousands . . . are thrown on the shore and there perish . . . . At such times the Indians would reap a good harvest in stripping them of feathers and down; these products being finer then (sic) the same from any geese, and command as ready a market . . . . The feathers can be obtained in any quantity at a dollar a pound in San Francisco. Here, with Indian help, ought to be a chance for a profitable business.
>
> A specimen . . . was sent to Washington for classification but, Agassiz being dead, it does not appear that anyone there could tell anything about it . . . .

FIGURE 7. Top: A photograph taken from the western side of Owens Lake, CA, between 1904–1916. Photo by A. A. Forbes, Courtesy of the Eastern California Museum, Independence, CA. Bottom: The situation in August 1993—a dry playa.

Its bill is long, sharp, and easily broken; something on the snipe order. The pedal appendages are more like flippers than feet, standing at such angles to the body, they are useless for any purpose except swimming.

Of its habitat little is known, other than its food consists of the billions of worms, the only other indigenous creature in those acrid waters.

Some think it is propagated from spawn like a fish, since its breeding places have never yet been discovered."

The lake must have been very attractive, but several reports of large-scale mortality (botulism?) strike a disquieting note. These include "fully two million dead 'ducks' piled around the lake" (*Inyo Register,* 4 April 1882).

In summary, for most of the historical period, from the 1840s (and perhaps as far back as 6000 BP) Owens Lake was a small analog of Great Salt Lake. Its demise left Mono Lake, 190 km to the north, as the closest alternative habitat for grebes and phalaropes.

THE LAKE THAT WASN'T THERE

The third largest saline lake in North America, unlike others in this report, did not exist when the Forty-niners reached California, and no one is credited with its discovery. The Salton Sea was created when an irrigation canal ruptured in 1905 and allowed the Colorado River to flow into the Salton Trough. By the time repairs were made in 1907 a nearly-fresh lake 60 km long remained. Enhanced by the proximity of irrigated agricultural fields, the area attracted sufficient waterfowl to be designated a National Wildlife Refuge in 1930.

The Sea's position as a northern extension of the Gulf of California places it on the flyway for many migrants, as well as for trapped vagrants trying to exit the Gulf of California (McCaskie 1970). It is a wintering area for 30,000 Canada and Snow geese (*Anser caerulescens*), and 140,000 ducks (including half of the Pacific Flyway population of Ruddies; Setmire et al. 1990), and is a migration stop for thousands of shorebirds. In January–March most of the New World population of Eared Grebe may pass through on its return trip to the nesting grounds (Fig. 8). Great concentrations of phalaropes have not been reported, however, probably because the Sea is too fresh and the food base is not suitable.

FIGURE 8. Eared Grebes staging in spring migration at the Salton Sea, California. Major fall staging areas include Mono Lake, California, Great Salt Lake, Utah, and Abert Lake, Oregon.

Problems with water supply and quality have given the Sea an unsavory reputation. Much of its inflow derives from agricultural and industrial runoff and municipal waste (Setmire et al. 1990). Massive dieoffs of fish (some from temperature changes) and shorebirds and waterfowl (from avian cholera and botulism) are not unusual, and in 1992 an estimated 150,000 Eared Grebes died from undetermined causes.

When the Sea formed its salinity was 3.5‰, and it would have attracted a great diversity of birdlife. Today it hovers at 40–43‰ and waterbird diversity on the sea itself is likely to be much reduced. Current salinities approach the upper limit for reproduction by some of its aquatic inhabitants (mainly, a rotifer, barnacle, cyclopoid copepod, nereid worm, and several fish, all but one of which were introduced). At 50‰, which could be realized within a decade (Hagar and Garcia 1988), a new community—perhaps based on brine flies and brine shrimp—might result, which could shift the composition of the avifauna toward that of Mono Lake.

Plans to maintain the Sea's environment (e.g., by controlling inflows, diking off segments) involve interests ranging from homeowners with beachfront property to irrigation districts and electrical utilities, as well as international concerns (some of the inflow is from Mexico). Inherently, they also involve a morass of agencies with overlapping and conflicting responsibilities. Whatever action (or no action) is taken, the Salton Sea, of all the lakes considered here, is the most likely to undergo massive changes in the 21st century.

DISCUSSION

The saline and alkaline lakes of the Great Basin are important breeding grounds and, especially, migratory stopover points for species that can tolerate their harsh and varied conditions. This is best evidenced by the fact that national wildlife refuges have been established at five of the eight lakes discussed in this report (Pyramid Lake, Carson Sink, Winnemucca Lake, Great Salt Lake, Salton Sea), and Western Hemisphere Shorebird Reserve Sites at three (Mono Lake, Carson Sink and Carson Lake, Great Salt Lake).

Scanty historical records over the past century and a half preclude detailed analyses of faunal changes in most areas. Even if these existed, they would be poor indices to changes at the population or species level, because the interior lakes constitute a series of disjunct and intermittently-available oases, whose users must be semi-nomadic and capable of shifting as environmental conditions require (e.g., Jehl 1988, Alberico 1993). In this regard, data on the White-face Ibis, a ground-nesting species of alkali marshes, are instructive. A survey in 1979–1980 revealed 24,500 breeding birds, 79% of which nested in Utah (Voeks and English 1981). When Great Salt Lake flooded in 1983–1989 and traditional nesting areas were submerged, numbers increased in the Malheur and Summer lakes areas of Oregon, southern Idaho, and the Stillwater/Carson Lake area (Ivey et al. 1988, Henny and Herron 1989, G. Keister, pers. comm.). When those areas dried in 1987–1992 (in 1992 there was virtually complete nesting failure at Stillwater and Malheur) the ibis again became common at Great Salt Lake (V. Roy, pers. comm.). Despite these shifts, there is no indication that the total population has undergone any appreciable change (D. E. Manry, pers. comm.).

The health of bird populations that use unstable habitats is to a large extent dependent on the availability of back-up sites that can be used when conditions change. Unfortunately, there is not much redundancy left in the saline and alkaline lakes of the west. Owens and Winnemucca lakes have been lost to demands of increasing human populations and will never be restored. The adequacy of long-term water supplies for the Carson Sink area is questionable. Engineering modifications to the water balance at Lake Abert are imminent, and others are being considered for the Salton Sea and Great Salt Lake. The Salton Sea is near a salinity threshold that could lead to its ecological reorganization. Of the lakes considered here only Mono, Pyramid, and perhaps Great Salt seem likely to remain largely unchanged in their ability to support current populations of migratory birds into the foreseeable future.

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