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A SUMMARY OF BIOLOGICAL INVESTIGATIONS CONCERNING THE GREAT SALT LAKE, UTAH (1861-1973)

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ABSTRACT.— The early stages in the history of biological investigation of the Great Salt Lake involved the identification and establishment of taxonomic relationships of the indigenous flora and fauna. A result of advancements in systematic biology is that many of the earlier names of organisms have been placed in synonomy. Recent interest in the lake has centered on biological productivity and interactions of components of the ecosystem. The creation of two ecologically distinct lakes by the construction of a railroad causeway has further enhanced the biological complexity of what was originally believed to be a lifeless body of brine.

Because of the late settlement of the Bonneville Basin, scientific investigation into the biological composition and biotic mechanisms of the Great Salt Lake was nonexistent before the latter half of the nineteenth century. An 1861 issue of *Scientific American* reported, "No living thing of any kind exists in the lake," ignoring Captain B. L. E. Bonneville's note of small animals in the water during his 1831-1833 explorations. By 1889 three species of algae (Farlow, 1879, cited in Kirkpatrick, 1934), a brine fly (Packard, 1871), and brine shrimp (Verrill, 1869) had been named from the lake, yet Jordan (1889) stated that no life could exist in the lake with the exception of brine shrimp. Schwarz (1891) investigated various forms of insect life adjacent to the lake and concluded that the brine fly, *Ephydra cinerea* Jones (as *Ephydra gracilis* Packard), was the only insect inhabitant of the lake. He made note of the adult flies' habits regarding oviposition and feeding in the water. Tilden (1898) reported five species of algae from the lake: *Aphanothece Utahensis* Tilden, *Polycystis packardii* Farlow, *Dichothrix utahensis* Tilden, *Enteromorpha tubulosa* (Kützing) Reinbold, and *Chara contraria* Braun.

It was now evident that the Great Salt Lake could support life and that additional biological inquiry was needed. Considerable interest and speculation centered around the introduction of marine organisms to the estuaries formed where fresh water entered the lake. Moore (1899) examined the chemical and physical characteristics of the lake and concluded that even with dilution, the waters would not support any introduced crustaceans or fish. The possibility of introducing oysters into the estuaries was considered, but he concluded that a self-replenishing colony could not exist from year to year, and commercial exploitation was not feasible.

Aldrich (1912) reported on the morphology and ecology of the brine flies *Ephydra cinerea* and *Hydropyrus* (as *E.*) *hians* (Say) from the lake, stating that a pulpy alga of the *Nostoc* group was the probable food of the *Ephydra* larvae. In his collection of notes on

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fauna in the lake, Vorhies (1917) stated that this *Nostoc* form was probably the alga *Alphanothece packardii* Setchell. He also commented on the viability of *Artemia* and *Ephydra* in various densities of lake water. Vorhies noted several protozoans in his culture flasks including an amoeba (similar to *Amoeba flowersi* Jones), a ciliate protozoan (similar to *Uroleptus*), and a species of *Euglena*. The alga *Chlamydomonas* (reported in Daines, 1917) appeared regularly and in great numbers in his cultures. He noted that the brine shrimp was never collected from the lake when the water temperature was below 9C. Complete absence of predators was suggested as an explanation for the great abundance of shrimp and brine flies.

In repudiation of Vorhies's (1917) comment that brine shrimp and brine flies were abundant due to lack of predators, Wetmore (1917) noted that a wide variety of waterfowl fed heavily on the animals in the lake. He stated massive production of offspring to be the most likely explanation for the abundance of *Artemia* and *Ephydra*.

A companion paper on the flora by Daines (1917, cited in error as Daniels) appeared with the observations of Vorhies on the fauna. Daines briefly mentioned Tilden's (1898) description of six algae and added a new one, *Chlamydomonas* sp. to the list. Two genera of diatoms (*Navicula* and *Cymbella*) were observed in the estuaries around the lake, and Daines concluded that they were adapted to dilute brines. He noted five bacteria, three being chromogenic, but offered no identifications. Daines noted a considerable size variation between the *Chlamydomonas* cells but through his experimentation concluded that it was not induced by differences in salinity.

The brine shrimp, *Artemia gracilis* Verrill was further observed and its general morphology described in some detail by Jensen (1918). He reported the optimum density for hatching and growth of *Artemia* to be between specific gravities of 1.044 and 1.089. The eggs would not hatch in a saturated brine solution.

Pack (1919) described a new species of protozoan, *Prorodon utahensis* Pack and studied the effects of brine dilution upon this species and another ciliate, *Uroleptus packii* Calkins. In less dense media, the animals increased in size, became more active, and developed more flexible and contractile bodies. Pack also believed that by "slowing down the rate of dilution, some of these Great Salt Lake forms may be transformed into fresh water animals."

Seville Flowers (1934), in his monograph on the vegetation of the Salt Lake area, reported the following algae as endogenous to the lake:

Aphanothece utahensis Tilden
Microcystis packardii Farlow (Tilden)
Oscillatoria tenuis var. *tergestina* (Kützing)
Oscillatoria tenuis var. *natans* (Kützing)
Chlamydomonas sp.
Tetraspora lubrica var. *lacunosa* Chauv.

The work of Flowers was followed by that of Kirkpatrick (1934) on the algal forms within the lake. Her conclusions touched upon the variety of organisms reported by earlier workers and are reproduced with added comments by this author:

1. There are five colonial forms of blue-green algae of the Great Salt Lake. Most of these forms did not thrive under laboratory conditions.
2. There are two species of *Chlamydomonas* in the Great Salt Lake. This form thrived at all densities (1.0145 to saturation).
3. Two species of diatoms. resembling *Navicula*, are present. They did not thrive in the weakest (sp. grav. 1.0145) nor the strongest (saturated) concentrations present.
4. A species of *Chroococcus* and one of *Gleocapsa* developed in the lower concentrations (sp. grav. 1.0225). They cannot be considered native lake forms.
5. A filament of *Oscillatoria* was seen twice. It is possible that this form exists in small quantities in the lake. It is very abundant in the hot springs along the shore and could readily be washed into the main body of water.
6. A great number of the species listed by former workers did not develop in the cultures, nor were they observed in examination of fresh material. It is possible that many of these forms came from extraneous sources, or were not able to survive the increased density of the lake water at its present low level.
7. The fauna observed in this experiment consists of three ciliates (*Uroleptus packii* Calkins, *Prorodon utahensis* Pack, and an unidentified species), one amoeba, one crustacean (*Artemia*) and one fly larvae (*Ephydra*).

The reported occurrence of diatoms by Daines (1917) and Kirkpatrick (1934) was further investigated by Ruth Patrick (1936). She found a variety of diatoms in the sediments of the lake, presumably originating from the Lake Bonneville era, but did not find any evidence of their currently living in the Great Salt Lake.

The bacterial composition within the lake was first investigated by Frederick (1924). Through the use of colonial morphology and several media, she isolated eleven forms, which she identified as the following:

Serratia salinaria (Harrison and Kennedy) Bergey
Cellulomonas subcreta (McBeth and Scales) Bergey
Bacillus freudenreichii (Miguel) Chester
Achromobacter solitarium (Ravenel) Bergey
Bacillus cohaerens Meyer and Gottheil
Flavobacterium arborescens (Frankland and Frankland) Bergey
Micrococcus sulflavus Chester
Achromobacter hartlebii (Jensen) Bergey
Bacteriodes rigidus (Dista) Bergey
Bacillus mycoides Flügge
Achromobacter album (Pagliani) Bergey

A brief mention of the brine shrimp, *Artemia fertilis* Verrill (*Artemia salina* Leach), *larval Ephldra*, the blue-green alga, *Aphanothece utahensis* as *Aphanothica packardii*, diatoms, and the green alga *Chlamydomonas* is made by Allee (1926). An observation of water bugs of the family Corixidae is also noted, probably referring to a similar observation by Schwarz (1891).

Woodbury (1936) provided the first comprehensive analysis of the lake ecosystem. His description of the aquatic system is brief, mentioning the apparent interspecific competition between two closely related species of *Ephydra* and *Artemia*. Several historical notes made by Fremont and Stansbury during early surveys were cited.

The bacterial composition within the lake was further investigated by Smith (1936). The majority of his results and conclusions are published in Smith and ZoBell (1937). Their conclusions, while not definitive, are of interest and are reproduced here:

> The attachment of bacteria to sterile glass slides submerged in Great Salt Lake indicates the presence of abundant and varied bacterial flora. Controlled experiments demonstrate that only living bacteria attach themselves to slides in appreciable numbers. This, together with the fact that micro-colonies develop on slides in the lake, indicates that the bacteria are multiplying in the lake and are not merely passive inhabitants. The inability of soil, sewage or marine bacteria to attach to slides in lake water supplies further proof for the latter contention. Most of the lake bacteria are small gram-negative rods besides other morphological varieties which do not fit into any conventional classification. The direct microscopic procedure offers possibilities for studying the seasonal and geographic distribution of bacteria in the lake.

A summary of research on the brine shrimp, *Artemia*, prior to 1936 is given in Relyea (1937), but no new data are presented.

An excellent compilation of research on the physiology of *Artemia salina* Leach appeared in the work of Quinn (1940). Magnesium ion concentrations of twice that in the lake did not appreciably change the time of nauplius emergence from the egg but did inversely affect the time of egg hatching. The time of emergence was found to vary inversely with the temperature, and effects of magnesium ion concentration on nauplii were restricted to the earliest developmental stages. A complete bibliography including many European articles is given.

A short paper presented by Rees (1942) presents a popular view of animal life within the lake. It is followed by an article by Behle (1942) listing four species of colonial nesting birds found on islands in the Great Salt Lake. Distribution and general ecology is presented for: American white pelican (*Pelecanus erythrorhynchos* Gmelin), double-crested cormorant (*Phalacrocorax auritus auritus* Lesson), Treganza great blue heron (*Ardea herodias* Treganza), and the California gull (*Larus californicus* Lawrence).

The amoeba noted by previous workers (Vorhies, 1917; Kirkpatrick, 1934; Woodbury, 1936) was described as *Amoeba flowersi* Jones by Jones (1944). He also described the Euglena seen by Vorhies (1917) and Kirkpatrick (1934), naming it *Euglena chamberlini* Jones.

Woodbury (1948) briefly mentioned the work of Quinn (1940) concerning salinity effects on *Artemia*. No new data are given. The Ephydridae of Utah (Jorgensen, 1956) lists *Ephydra cinerea* Jones as the most common brine fly from the lake, with *E. auripes* Aldrich, *E. riparia* Fallen (as *E. subopaca*) and *Hydropyrus* (as *E.*) *hians* (Say) also being reported by various other collectors.

Evans and Thompson (1964) list a new genus of ciliate protozoan, *Pseudocohnilembus*, occurring in the lake. Only one species, *P. persalinus* Evans and Thompson, was collected. Further work by Professor Evans and his students has resulted in the isolation of an additional ciliate, *Euplotes parsalinus* Reddy from the lake (Reddy, 1971).

Population pressures and its problems were becoming evident when McDonald (1956) investigated the effects of pollution upon lake organisms. Dissolved oxygen concentrations were found to be below 3.3 mg/liter with localized decomposition of brine organisms being primarily responsible for the oxygen demand. He reported that an experimental mixture of 2 percent commercial oil and gasoline added to lake water containing the alga *Chlamydomonas* resulted in complete elimination of cells within 45 hours.

A comprehensive study of the bird life associated with the lake was authored by Behle (1958). As the lake lies within the Pacific Flyway, there are numerous local and transient birds associated with its marshes, constituting the major predatory source for the macrofauna.

Evans (1960) listed five new genera of protozoa and three unidentified types from the lake. *Crystigera*, *Cyclidium*, *Euplotes*, and *Oikomonas* were believed to be bacterial feeders. *Podophyra* was predaceous upon *Euplotes*. An amoeba and two unidentified ciliates were also observed. *Cristigera* exhibited optimum growth in salt concentrations of 1 to 18 percent; its growth completely declined at 23 percent salt. Cysts of *Cristigera*, however, could survive long periods in a saturated salt solution. Preliminary tests on other protoza indicated that growth is inhibited at 15-18 percent salt concentration. Evans concluded that *Cristigera* and the amoeba were specialized halophilic protozoa and that certain of the other species of protozoa may be salt-tolerant, freshwater forms.

The occurrence of algal biostromes or tufa precipitated from the brine as a result of the action of blue-green algae was mentioned by Flowers (1934). Carozzi (1962) reported *Aphanothece packardii* to be the most predominant blue-green, forming the biostromes in distinct morphological zones. He concluded that the algae have no characteristic growth pattern of their own, but have developed on raised areas separating a system of erosional channels extending at right angles to the shoreline.

A fairly complete summary of plant and animal species found in and around the Great Salt Lake appeared in Flowers and Evans (1966). Their work lists two species of blue-green algae, *Coccochloris elabens* Drouet and Daily and *Entophysalis rivularis* (Kützing) Drouet, and two undescribed species of green algae, *Chlamydomonas*, as inhabiting the lake proper. The listing of bacteria follows that of Frederick (1924) with several forms listed in synonomy. The brine shrimp, *Artemia salina* is mentioned as the most conspicuous animal. The brine flies *Ephydra cinerea* Jones and *E. hians* Say are the only insects reported within the lake. The list of protozoa appearing in Evans (1960) was revised and expanded, listing the following ciliates:

Uroleptus packii Calkins
Chilophyra utahensis (Pack)
Podophyra sp.

Euplotes sp.
Pseudocohnilembus sp.
Cothurnia sp.

Two unidentified amoeba were noted as common, and several species of flagellates including *Tetramitus*, *Oikomonas* and at least two others were seen in large numbers from the lake and nearby salt ponds. Mention is made concerning the deposition of carbonate tufa by blue-greens, but the exact mechanism is unknown. Vegetation surrounding the lake is well described and its distribution noted.

Gaskill (1970) reported on waterfowl commonly associated with the southeastern shore of the Great Salt Lake concluding that coots were the most prevalent of nesting birds (39 percent of total), with cinnamon teal, redhead, mallard, and pintails of considerable importance.

The report of a National Science Foundation student-originated studies program (Carter, 1971) considered ecological relationships within the Farmington Bay Estuary of the Great Salt Lake, and the general terrestrial ecology of Antelope Island State Park. Portions of the aquatic study are relevant to the lake biology and are presented here.

The estuary is less polluted now (1971) by coliform bacteria than it was in 1965. The coliforms are more heavily distributed on the estuary bottom than in the upper layers of water. Most coliforms are killed or fail to multiply in NaCl concentrations greater than 5.5 percent, with some of the bacteria being sensitive to concentrations of as little as 1.8 percent. The freshening of Farmington Bay could cause a definite increase in the coliform population.

There are large numbers and many species of protozoans living in the estuary resulting from freshening of the lake due to construction of the causeway from Syracuse to Antelope Island. Because of the increase in the protozoan population, it is reasonable to expect an increase in the overall biological productivity as protozoans are an important food and energy source.

The distribution, number, and species diversity of zooplankton and phytoplankton were established. Through comparison with the water chemistry of samples taken at the same locations, it was found that the distributions of *Artemia salina*, *Diaptomus*, sp., a Corixid, *Daphnia* sp., and *Nodularia* sp. are dependent on the salinity. A predator-prey relationship between the Corixid and *Artemia salnia* was suggested, and it is concluded that the introduction of marine game fish or fresh water fish to the area for sport fishing is not feasible.

The construction of a rock-filled railroad causeway between Little Mountain and Lakeside in 1957 resulted in the creation of two ecologically distinct lakes due to salinity imbalances. Its effect on the biota was reported by Gillespie, Wirick, and Stephens (1971). They concluded that the saline waters of the Great Salt Lake provided an extremely rigorous, and therefore relatively simple ecosystem. The northern basin contains saturated brine with a depauperate biota consisting of *Dunaliella salina* Teodoresco plus unidentified protozoa and bacteria. In the southern basin, two major energy-flow sequences dominate the system: a planktonic sequence consisting of (*Dunaliella*) → (*Artemia*) and a benthic sequence consisting of (blue-green algae + detritus) → (*Ephydra*). There is some crossover in that much of the detritus consists of dead *Artemia*, and *Artemia* will feed on benthic algae and detritus when *Dunaliella* are scarce.

Further work by Wirick (1972) demonstrated that the main phytoplankter, *Dunaliella viridis* Teodoresco (previously reported as a *Chlamydomonas*) exhibited one bloom per year in April. The zooplankter, *Artemia salina* is present and grazing *Dunaliella* only when the water temperature is above 6C. Construction of a mathematical simulation model suggested that the growth rate of the *Dunaliella* population is light limited and density dependent at high algal concentrations.

Porcella and Holman (1972) concluded that inorganic nitrogen is apparently the limiting factor for growth of phytoplankton in the Great Salt Lake water. Carbon may also be limiting. Phosphorus, iron, and other trace elements seem to be in abundant supply. Their observations were confirmed by algal bioassays. Growth and reproduction of the brine shrimp on *Dunaliella* alone was superior to yeast alone as a food source. The optimum utilization by the brine shrimp was about 1,000 algal cells per brine shrimp per day. Different concentrations and ages of added algae had no apparent effect on whether the mature brine shrimp produced live young (nauplii) or resistant cysts. It was their belief that a feasible aquaculture based on*Dunaliella* sp. and *Artemia* sp. could be developed for brine shrimp isolated from the Great Salt Lake. Production of algae and brine shrimp in lake enclosures may be increased by addition of specific nutrients.

Basic schemes for energy flow within the north and south lake basins were presented by Stephens and Gillespie (1972). They found that the northern basin supports a depauperate biota consisting primarily of an alga, *Dunaliella salina*, several protozoa, and bacteria. The southern basin exhibits two energy-flow systems with only minor interactions: the planktonic system with a dominant phytoplankter, (*Dunaliella viridis*), and a single zooplankter, (*Artemia salina*); and a benthic system of blue-green alga (*Coccochloris elabens*), detritis, and brine fly larvae (*Ephydra*). The only outflow from either system occurs when birds feed upon the shrimp or fly larvae. The *Dunaliella* population seems to be limited early in the calendar year by temperature and light. *Dunaliella viridis* reaches its peak population density (24 x 10^6/liter) in April and its decline to less than 1 x 10^6 cells/liter) occurs in May and June as a consequence of the rapidly expanding *Artemia salina* population. The availability of the nutrients nitrogen and phosphorous does not seem to be a limiting factor for *Dunaliella*.

The apparent conflict of the Porcella-Holman study (1972) and that of Stephens-Gillespie (1972) regarding limiting factors to phytoplankton growth is currently under investigation by Stephens (1973). Initial conclusions indicate that *Dunaliella* is (1) light limited during the April-May bloom and (2) nitrogen, carbon, and possibly vitamin limited later in the year. Grazing by *Artemia* could prevent additional algal blooms even if necessary nutrients were available.

Most recently, Van Auken and McNulty (1973) published on the factors limiting growth in laboratory cultures of *Dunaliella* sp.

isolated from the Great Salt Lake. Optimum growth was obtained under the following conditions: (1) temperature 32 C, (2) NaCl 19.2 percent (w/v), (3) CO_2 1-2 percent at a rate of 2.2 ml/min/ml of culture media, (4) light intensity of 25-35 klux, (5) pH 5.8-6.5. The K^+/Na^+ ratio should not be more than 0.1. The specific growth constant for this halophyte under the above conditions was 0.069 hrs^{-1}, which is equal to a doubling time of 10 hours.

Chemical control of the massive swarms of *Ephydra* in the beach areas was reported by Nabrotzky, Rosay, and Sadler (1973). Control lasting several hours to several days was obtained using both malathion and Dowco 214 insecticides. At the concentrations applied, no damage to *Artemia* or water bugs (Corixidae) was evident. An indigenous wasp parasite of *Ephydra* larvae collected near the lake indicates biological control of the brine flies may be possible.

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