Relationships among total dissolved solids, conductivity, and osmosity for five *Artemia* habitats (Anostraca: Artemiidae)

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RELATIONSHIPS AMONG TOTAL DISSOLVED SOLIDS, CONDUCTIVITY, AND OSMOSITY FOR FIVE ARTEMIA HABITATS (ANOOSTRACA: ARTEMIIDAE)

Nicholas C. Collins¹ and Gray Stirling¹

ABSTRACT.—Graphs allowing interconversion between various physical chemical parameters are presented for five Artemia habitats in the western USA. Both the mean osmosity and its typical yearly range differ greatly among habitats. Consequently, Artemia populations provide an interesting opportunity to study physiological and life history adaptations to differing degrees of habitat stability.

Populations of Artemia, the brine shrimp, exist in isolated hypersaline environments throughout most of the world (McCarraher 1972). Their source waters span the entire natural spectrum of ion ratios (Cole and Brown 1967) and range from the massive and relatively permanent Great Salt Lake to temporary ponds 50 m to diameter (e.g. Broch, 1969; Khalaf et al. 1977). Not surprisingly, the individual populations exhibit morphological, physiological, developmental, and genetic differences that indicate they are locally adapted (e.g. D'Agostino 1965, Clark and Bowen 1976; Claus et al. 1977, Collins 1977).

Because the resting cysts of these populations are easy to collect, transport, store, and hatch, Artemia populations are excellent subjects for comparative studies of genetics (Barigozzi 1974, Clark and Bowen 1976), physiology of ion regulation (e.g. Geddes 1975a, b, c), and life history tactics (Collins 1977, Claus et al. 1977). Many such studies have involved comparisons of the performance of various strains grown in a common medium, usually diluted or concentrated seawater. An alternate approach, which accommodates some strains that will not grow well in sea water, involves growing them each in their own source water, but at a common osmotic pressure. This alternative requires measurement of the osmotic characteristics of various dilutions of water from each source lake, a time-consuming process requiring osmometers that are both expensive and uncommon. To reduce the necessity for future osmometric measurements for studies of Artemia populations in the western United States, this paper presents relationships between osmosity and more easily measured parameters for source waters of five populations. Data on pH changes with source concentration and information on the natural range of concentrations for each source are also presented.

METHODS

Source waters from Arizona, New Mexico, Nebraska, and Washington, collected during 1976 and 1977, were filtered and diluted or concentrated by evaporation. Locations for each source are specified in the references in Table 1. Total dissolved solids (TDS) concentrations were determined by evaporating five or ten ml samples to a constant weight at 100 C. Salt scale had to be repeatedly broken to insure completion of the drying process. Drying at temperatures higher than 100 C resulted in steam explosions within salt masses that scattered the salt and biased the determinations.

Conductivity meter readings were converted to specific conductance at 20 C using an NaCl calibration curve based on Wolf, Brown, and Prentiss (1975).

Specific gravity at 20 C was measured gravimetrically using individually calibrated 50 ml volumetric flasks. Each determination

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is the average of duplicate measurements.

Osmosity, the molar concentration of NaCl having the same freezing point or osmotic pressure as the measured solution, was determined with a Wescor vapor pressure osmometer. The microvoltmeter output was calibrated with a series of NaCl solutions whose osmotic properties were assumed to correspond with Wolf et al. (1975). Two to five determinations were averaged for each data point in the figures.

Results

For three of the five sources (Figs. 1–3) osmosity is closely, linearly related to TDS. Where Y is osmosity, X is TDS, n is the number of measurements, and r is the product-moment correlation coefficient, the relationships for Penley Lake (Washington), Green Pond (Arizona), and Lily Lake (Nebraska) are respectively:

![Graph showing relationships between TDS and conductivity and osmosity for Penley Lake.](image)

Fig. 1. Relationships among TDS, conductivity (open circles), and osmosity (closed circles) for Penley Lake, near Omak, Washington (Broch 1969). Numbers below upper margin are specific gravity measurements and those above lower axis are pH values for indicated TDS levels.
The TDS-osmosity relationships for the other two lakes (Figs. 4, 5) did not appear to be linear, and were drawn by eye. Similarly, the curvilinear TDS-conductivity relationships for all lakes were drawn by eye.
Discussion

Generally, conductivity is the most convenient indicator of osmosity or TDS. The natural concentrations of these source lakes fall well above the highest scale of most existing conductivity meters, but Figs. 1-5 will allow rough predictions of TDS or osmosity from conductivity measurements of samples diluted to within the range of such meters. In such cases the errors in any prediction based on the graphs will be multiplied by the dilution factor. At the highest source concentrations conductivity is not a precise predictor of TDS or osmosity (Figs. 4, 5). For such solutions an accurate dilution can be made for conductivity measurement, or TDS can be measured directly. Inaccuracies in TDS mea-

Fig. 3. Relationships among physical-chemical parameters for Lily Lake, near Alliance, Nebraska (McCarraher 1970). Legend as in Figure 1.
measurements from water inclusions in the crystalizing salt mass can be eliminated by using a micrometer syringe for applying precisely measured small volumes (< 1 ml) to a preweighed filter paper circle. Such a technique will also allow much faster determinations than the one we used.

Hydrometer measurements of specific gravity are often reported as a measure of concentration. Although this method appears to be quick, straightforward, and suitable for field measurements, our experience indicates even marginally accurate results require careful control of water temperature, wind, and cleanliness of the hydrometer that together preclude most field measurements. In

Fig. 4. Relationships among physical-chemical parameters of Jesse Lake, near Alliance, Nebraska (McCarraher 1970). Legend as in Figure 1.
the laboratory, TDS measurements or gravimetric density determinations are almost as easy as hydrometer readings, if a conductivity meter is not available.

A summary of natural osmosity and TDS levels from western *Artemia* habitats (Table 1) indicates that different populations experience not only very different ion ratios and mean osmosities, but also very different seasonal ranges in source osmosity. Western North American *Artemia* populations therefore provide an interesting opportunity to

![Graph showing the relationship between conductivity, osmotic pressure, and total dissolved solids in Zuni Salt Lake.](image)

*Fig. 5. Relationships among physical-chemical parameters of Zuni Salt Lake, near Quemado, New Mexico (Bradbury 1971). Legend as in Figure 1.*
identity the genetic, physiological, and life history characteristics that evolve in response to variability of environmental conditions, and in response to substantial differences in length of the growing season.

NOTE ADDED IN PROOF: Recent talks with Nebraska residents revealed that the lake referred to in this paper and in Collins (1977) as Lily Lake of McCarraher (1970, 1972) is actually an unnamed smaller lake slightly northwest of the true Lily Lake. The range of osmotic for this lake is unknown; therefore the figures for it in Table 1 should be disregarded.

ACKNOWLEDGMENTS

The National Geographic Society, the Natural Sciences and Engineering Research Council of Canada, and the University of Toronto supported this work financially. I thank Mr. Drew Platt for permission to sample Green Pond, Gerald Cole, J. P. Bradbury, and Sarane Bowen for information on sampling sites, and R. W. Cummins and J. Svoboda for access to the osmometer. LeeAnne Wilson and John Stoneman provided excellent technical assistance.

### Table 1: Comparisons of physical and chemical characteristics of six Artemia sources in the western USA

<table>
<thead>
<tr>
<th>Water body</th>
<th>Major salt</th>
<th>Observed TDS range (g/l)</th>
<th>&quot;Typical&quot; annual osmotic range (moles/l)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Great Salt Lake, Utah</td>
<td>NaCl</td>
<td>130–300</td>
<td>2.2–2.25</td>
<td>Hands and Hahl 1966</td>
</tr>
<tr>
<td>Jesse Lake, Nebraska</td>
<td>NaCO₃</td>
<td>52–87</td>
<td>0.57–0.90</td>
<td>McCarraher 1970, 1972</td>
</tr>
<tr>
<td>Lily Lake, Nebraska</td>
<td>NaCO₃-Cl</td>
<td>12–69</td>
<td>0.16–0.76</td>
<td>McCarraher 1970, 1972</td>
</tr>
<tr>
<td>Green Pond, Arizona</td>
<td>NaCO₃-Cl</td>
<td>61–112</td>
<td>0.98–1.8</td>
<td>Cole and Whiteside 1965</td>
</tr>
<tr>
<td>Penley Lake, Washington</td>
<td>Na₂SO₄</td>
<td>33–230</td>
<td>0.24 dryness</td>
<td>Broch 1969</td>
</tr>
<tr>
<td>Zuni Salt Lake, New Mexico</td>
<td>NaCl</td>
<td>17.5–350</td>
<td>0.35–5.3 +</td>
<td>Bradbury 1971</td>
</tr>
</tbody>
</table>

*Range of values recorded in literature and personal observations. Annual range is usually smaller.

**Includes only the period during which active Artemia are present. For some lakes, only one year's data are available, so nothing is known about between-year differences.


