POTENTIAL USE OF GREAT SALT LAKE WATER FOR LOBSTER CULTURE

Roger W. Mickelsen[1], Richard A. Heckmann[1], and Rex C. Infanger[1]

ABSTRACT.— Three experiments were conducted to determine if water from the Great Salt Lake altered in chemical composition and dilution can be used successfully to sustain a species of hermit crab *Pagarus sp.* and the American Lobster (*Homarus americanus*). Great Salt Lake water altered by freshwater dilution will not sustain the hermit crab or the American lobster. Great Salt Lake water can be altered chemically by dilution to support growth of the American lobster.

American lobsters maintained in Instant Ocean synthetic sea water (control) grow at a more rapid rate than animals sustained in altered Great Salt Lake water. A plastic primer coat used for plastic tank repair appears to be a moult inhibitor for the American lobster. Lobsters afflicted by the primer coat are not able to reverse the damage by continued moults.

The American lobster, *Homarus americanus* Milne-Edwards, occurs along the Atlantic Coast of Canada and the United States, where it lives on the continental shelf at depths of 10 to 210 m. Many attempts have been made to culture lobsters to satisfy the rising demand and to supplement decreasing catches (Graham 1973). The most successful work, using natural sea water, is that done at the Massachusetts State Lobster Hatchery. Lobster larvae have been reared with 80 percent survival through the four larval stages (Fig. 1) and grown to market size in two years instead of the normal six years (Hughes, Sullivan, and Shleser 1972).

The Great Salt Lake, in northern Utah, has a salt content 4 to 6 times greater than the world's oceans. As early as 1879, attempts were made to propagate oysters, eels, and marine fish in the estuaries of Great Salt Lake. Failure of these projects was attributed to frequent high winds, which altered the salinity of the estuaries above lethal levels (Miller 1969).

Chemical analyses indicate qualitative similarities between the ionic composition of the Great Salt Lake and sea water, with only quantitative differences as shown in Table 1 (Sverdrup, Johnson, and Fleming 1942). This suggests that water from the Great Salt Lake diluted and altered chemically could support the American lobster.

The objectives of this study are to determine whether (1) chemical additions and various dilutions of water from the Great Salt Lake can support the American lobster, and (2) if alteration of this high saline water can promote growth and a high percentage of survival. Data from these studies will be used as a base for further experimentation to determine if declining supplies of lobsters could be supplemented with this new technique.

Review of Literature

Lobster Culture

LIFE HISTORY.— The life history of the American lobster, which is typical of most decapods, is characterized by fertilized eggs developing into larvae which remain as pelagic organisms for a short time before they become benthic organisms.

Dow (1949) determined that copulation occurs within a 48-hour period after the female moults. The initial phase of mating, which occurs in the summer, requires the release of a pheromone by the female. This attracts the male and alters his normally aggressive behavior. According to Hughes and Mathiessen (1962), courtship may require 30 minutes, whereas copulation generally lasts less than five. After copulation the sperm are

[1]Department of Zoology, Brigham Young University, Provo, Utah 84602.

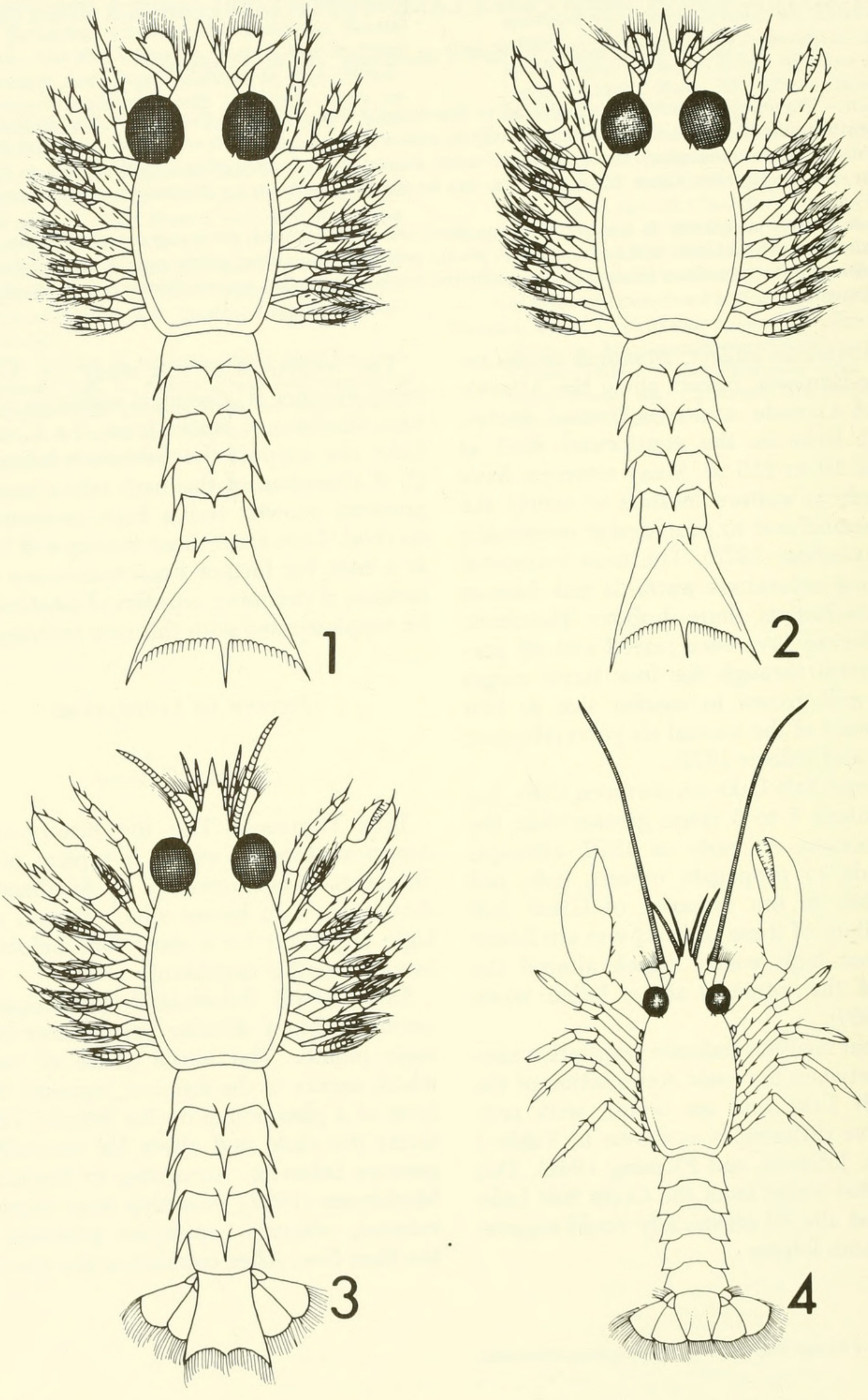

Fig. 1. The first four larval stages of *Homarus americanus* drawn from scanning electron micrographs (Heckmann et al. 1978).

stored in the seminal receptacle while the immature eggs complete development. Bardach, Ryther, and McLarney (1972) estimated that ovulation occurs between 9 and 13 months after copulation; eggs may number 125,000. Sperm fertilize the eggs as they are deposited onto the nonplumose hairs of the swimmerets. The eggs remain glued to the swimmerets for another 10 to 12 months before hatching.

Early in the summer the lobster larvae hatch beneath the female's tail and float away (Hughes 1973). Total time for the larvae to develop and emerge from the eggs is between 19 and 25 months (Bardach, Ryther, and McLarney 1972). Hughes (1973) found that at this point the larvae look like tiny shrimp rather than lobsters, and after three moults they acquire well-developed claws and external morphology of the adult, sink to the bottom, and assume their characteristic benthic existence.

Hatching and care of larvae.— Lobster culture began in France in 1865 according to Dow (1949), and cultural techniques, which were generally unsuccessful, were developed somewhat later in the 1890s and early 1900s in other countries (Norway, Holland, Great Britain, Canada, Newfoundland, and the United States). Survival of larval lobsters to the fourth stage was still only 4.4 percent in 1947 and 1948 at the U.S. Fish and Wildlife hatchery at Boothbay Harbor, Maine (Dow 1949).

Initial problems encountered by Dow (1949) included the use of (1) brass fittings in water supply systems (copper in brass is highly toxic to lobsters), (2) ambient seawater for hatching systems, and (3) ground liver as a food source. These problems were corrected and survival rates increased when brass fittings were removed from the water supply system, hatchery water was heated, and the liver was replaced with ground mussel.

Larval rearing equipment was improved by Hughes and Matthiessen (1962), who used a plastic circulating tank and a perforated central cylinder placed around a standpipe (Fig. 2), thus removing the need for metallic fittings. Hughes (1973) later modified the apparatus by adding a fiberglass tank with a concave bottom, along with the plastic circulating device (Fig. 2). Larval survival in-

Table 1. Comparison of ions present (ppm) in Great Salt Lake water and sea water.

Ion	Sea water*	Great Salt Lake water**	Ratio
Chlorine	18,980	68,500	1:3.6
Sodium	10,561	44,000	1:4.2
Sulfate	2,560	8,400	1:3.3
Magnesium	1,272	1,703	1:1.3
Calcium	400	840	1:2.1
Potassium	380	4,000	1:10.5
Bicarbonate	142	493	1:3.47
Bromine	65	trace	
Strontium	13	trace	
Silicate	0.04–8.6	0.0	
Boron	4.6	15.35	1:3.3
Flouride	1.4	0.64	1:0.45
Aluminum	0.16–1.9	unknown	
Iron	0.002–0.02	3.8	1:1900–1:190
Lithium	0.1	unknown	
Phosphorus	0.001–0.10	3.45	1:3450–1:34.5
Copper	0.001–0.09	0.19	1:190–1:2.1
Iodide	0.05	unknown	
Zinc	0.005–0.014	0.29	1:58–1:20.7
Manganese	0.001	0.28	1:280
Vanadium	0.0003	unknown	
Cobalt	0.0001	unknown	

*Sverdrup, Johnson, and Fleming (1942).
**Utah State Department of Health (1972).

creased from 4.4 to 42.6 percent by using this equipment.

GROWTH RATES AND MATING.— Hughes (1972) has shown that sexually mature lobsters can be produced in two to three years by raising water temperatures to 22 C, whereas at ambient temperatures they require between seven and eight years to mature. He also found that, though laboratory mating was relatively easy to accomplish, egg extrusion required a minimum coverage of 46 cm of water (Hughes 1973).

Perkins (1972) demonstrated that, by monitoring the development of the lobster and manipulating the water temperature, embryonic growth could be altered to produce larvae throughout the year. The minimum period of time was 11 months after mating (Bardach, Ryther, and McLarney 1972).

Shleser (1974) has shown that live brine shrimp, *Artemia salina*, produce the highest growth rates of any diet tested for lobster growth to date. Growth rates were improved by Conklin, Devers, and Shleser (1975), who fed the algae *Dunaliella promolecta* to brine shrimp prior to harvesting. Synthetic diets composed of wheat gluten, casein, corn starch, lipids, vitamins, and minerals developed by Conklin, Devers, and Shleser (1975) have produced promising results. However, no diet has yet been formulated to equal the growth rates produced by live brine shrimp.

Gallagher and Brown (1975) observed that synthetic sea water mix, Instant Ocean, produced higher growth rates in juvenile lobsters than did natural sea water. This increased growth may be due to higher pH values maintained in Instant Ocean because of lower bacterial levels.

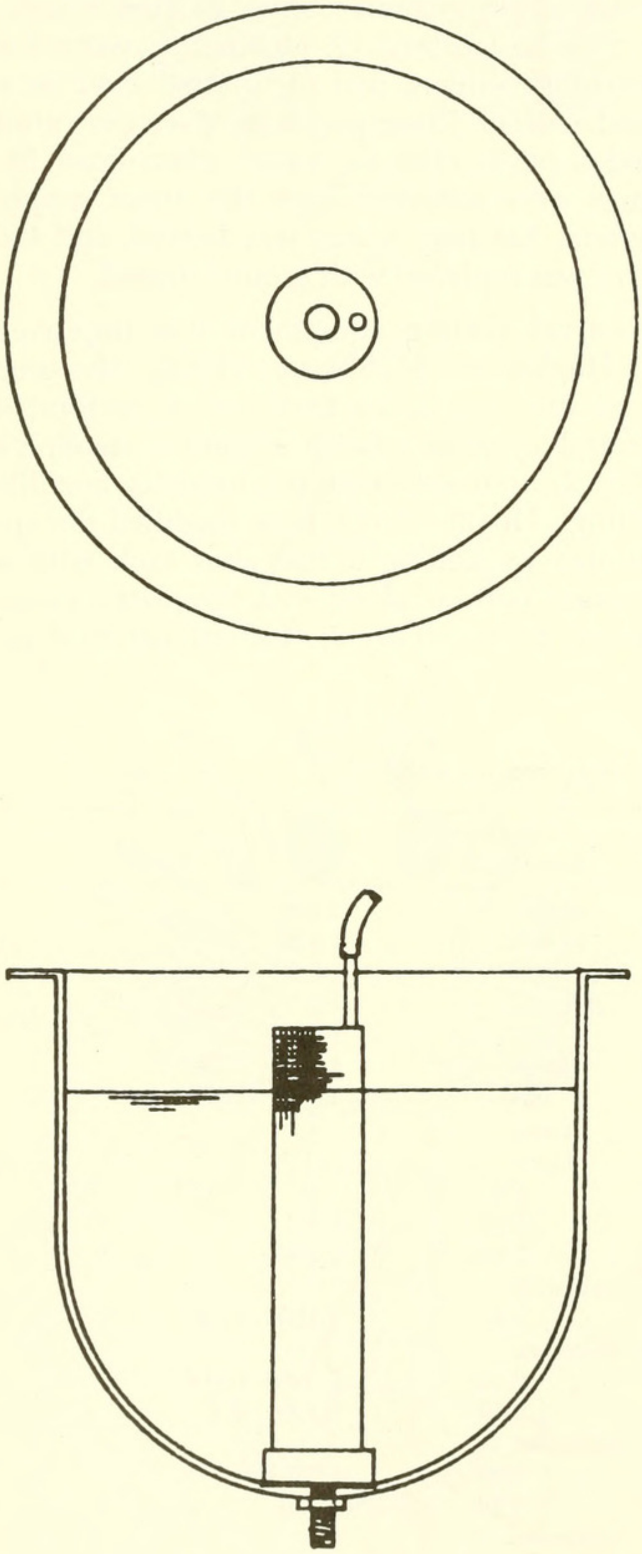

Fig. 2. General views of larval rearing tank (Hughes, Shleser, and Tchobanoglous 1974).

Great Salt Lake, Utah

PHYSICAL CHARACTERISTICS.— According to Miller (1969), the Great Salt Lake has a salinity of approximately 105 ppt in the southern half to approximately 250 ppt in the northern half. The Bear, Weber, and Jordan rivers, which account for a majority of the freshwater input, enter the southern half of the lake. According to Stephens (1974), this imbalance of freshwater inflow has caused salt migration to the north arm, resulting in subaqueous precipitation of sodium chloride and a reduction of the salinity of the south.

BIOLOGY.— The Great Salt Lake supports large populations of invertebrates, but no fish. According to several authors (Stephens 1974), brine shrimp (*Artemia salina*), brine flies (*Ephydra hians* and *Ephydra cineria*), waterboatman (*Trichorixa interiores*) (Winget, pers. comm.), 7 species of protozoans (Jones 1946), and 23 species of diatoms (Felix, pers. comm.) are present.

METHODS AND MATERIALS

GREAT SALT LAKE WATER.— Samples of Great Salt Lake water were collected from the southern half of the lake at the north dike of Silver Sands Marina (Fig. 3). These were returned to Brigham Young University, where they were sealed in five-gallon buckets and stored in darkness.

EXPERIMENTAL ANIMALS.— Hermit crabs were collected from the intertidal zone of the Pacific Ocean near Redondo Beach, California. These were transported to Provo in 5-gallon buckets filled with sea water oxygen-

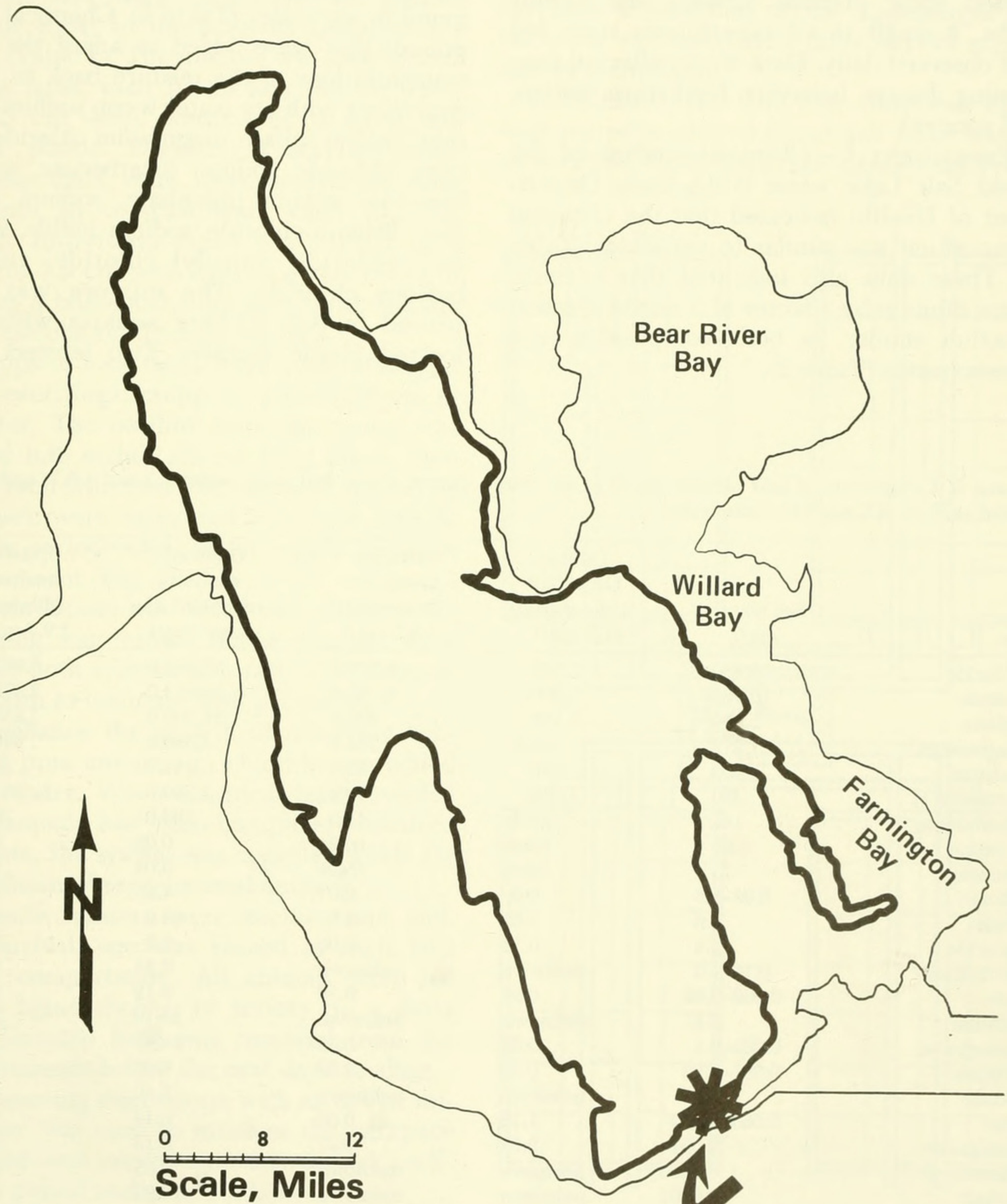

Fig. 3. Sampling site (arrow) for Great Salt Lake water on south shore of Great Salt Lake.

ated with battery-operated aerators. They were maintained at BYU in 20-gallon aquaria filled with Instant Ocean (synthetic sea water) and fed brine shrimp, chopped clams, and frozen shrimp.

Juvenile lobsters were obtained air freight from the Massachusetts State Lobster Hatchery. Animals were packed in large plastic bags filled with sea water and oxygen and placed in styrofoam shipping boxes.

Three different experiments were conducted using juvenile lobsters and hermit crabs. Animals in all experiments were fed and observed daily. Data were collected concerning disease, behavior, food consumption, and survival.

EXPERIMENT I.— Chemical analysis of the Great Salt Lake water (Utah State Department of Health) indicated that the chemical composition was similar to sea water (Table 1). These data also indicated that a freshwater dilution by a factor of 3 would create a situation similar in both composition and concentration (Table 2).

A mixture with a salinity of 34 ppt was prepared by adding one part Great Salt Lake water to two parts tap water. The mixture was placed in a 37-liter aquarium equipped with an undergravel filter with calcium carbonate as the substrate. Five hermit crabs were placed in the aquarium.

EXPERIMENT II.— One part of Great Salt Lake water was diluted with 9.7 parts tap water. This dilution reduced the potassium ion concentration to 380 ppm, the amount found in sea water (Table 2). Chemical compounds that were added to adjust the ionic concentrations of the mixture back to levels equivalent with sea water were: sodium chloride, sodium sulfate, magnesium chloride, calcium chloride, sodium bicarbonate, sodium bromide, sodium phosphate, sodium molydate, lithium chloride, sodium iodide, aluminum chloride, vanadyl chloride, and cobaltous chloride. The mixture was then placed in two 37-liter aquaria with perforated plastic dividers. Two lobsters were

TABLE 2. Comparison of ions present (ppm) in sea water, diluted Great Salt Lake water 1:3 and 1:8.7, and an updated analysis of Great Salt Lake water.

Ion	Sea water[1] mg/l	Diluted Great Salt Lake water[2] 1:3 mg/l	Diluted Great Salt Lake water 1:8.7 mg/l	Updated analysis Great Salt Lake water[3] mg/l	Updated analysis diluted 1:9.7 mg/l
Chloride	18,980	17,125	6,523.8	57,982.0	5,977.52
Sodium	10,561	11,000	4,190.5	28,813.0	2,970.41
Sulfate	2,560	2,100	800.0	12,500.0	1,288.65
Magnesium	1,272	425.8	162.2	3,360.0	346.39
Calcium	400	210	80.0	244.0	25.15
Potassium	380	1,000	380.1	3,700.0	381.44
Bicarbonate	142	123.3	47.0	299.0	30.82
Bromine	65	trace	trace	0.09	0.01
Strontium	13	trace	trace	0.04	0.004
Silicate	0.04–8.6	0.0	0.0	4.6	0.47
Boron	4.6	3.83	1.7	18.0	1.85
Flouride	1.4	0.16	0.06	8.2	0.84
Aluminum	0.16–1.9	unknown	unknown	0.24	0.02
Iron	0.002–0.02	0.95	0.36	0.13	0.013
Lithium	0.1	unknown	unknown	16.10	1.66
Phosphorus	0.001–0.1	0.87	0.32	24.5	2.53
Copper	0.001–0.09	0.05	0.09	0.05	0.005
Iodide	0.05	unknown	unknown	0.46	0.005
Zinc	0.005–0.014	1.16	0.03	0.14	0.014
Manganese	0.001	0.07	0.27	0.15	0.015
Vanadium	0.0003	unknown	unknown	0.03	0.003
Cobalt	0.0001	unknown	unknown	0.29	0.029

[1]Sverdrup, Johnson, and Fleming (1942).
[2]Utah State Department of Health (1972).
[3]Ford Chemical Laboratory and Western Standard Laboratory (1976).

placed in each of the aquaria and fed a diet of frozen brine shrimp.

Experiment III.— Great Salt Lake water was diluted by adding 9.7 parts distilled water to one part Great Salt Lake water. The ionic concentration was adjusted to levels consistent with sea water by addition of sodium chloride, magnesium chloride, calcium chloride and sodium bicarbonate. No further ions were added inasmuch as a chemical analysis indicated that the concentration of all other ions being considered was greater than or equal to the amounts found in sea water (Table 2). The mixture was then placed in four tanks, each 70 cm long, 40 cm wide, and 15 cm deep, constructed of glass and acrylic plastic. Dividers of acrylic plastic 1.25 mm thick were used to separate each tank into 28 compartments, each 10.2 cm square. Individual tanks were filled to a depth of 7.6 cm with broken oyster shells to serve as a biological filter and buffer for the water circulating through the tank.

Groups of four tanks were connected to a single centrifugal pump by pipes 1.25 cm in diameter. The outflow from the pump was divided into eight 1.25 cm PVC pipes. Two pipes, each with two 0.31 cm holes drilled 10 cm apart, were supported over each tank to provide an individual water supply for each compartment (Fig. 4).

Instant Ocean was mixed and added to the remaining four tanks. Water changes were made in both systems at a rate of 25 percent per month to maintain high pH values.

To enhance the growth of nitrifying bacteria, 7 ppm ammonium chloride was added to the water. When chemical tests revealed that ammonia had been completely oxidized to nitrate, the system was considered safe for the addition of experimental animals.

Juvenile lobsters were acclimatized and, upon arrival, one was placed in each 10.2 square compartment. All animals were fed frozen brine shrimp to satiety on a daily basis. Uneaten food was removed from the compartments before the next day's feeding.

A dissecting microscope with an ocular micrometer was used to measure the carapace length of each lobster after a two-week acclimation period and after 60 days.

Salinity, temperature, pH, nitrite, and dissolved oxygen levels were measured daily with appropriate meters. Nitrite was measured with a Bausch and Lomb Spectrophotometer.

Results

Experiment I.— The five hermit crabs subjected to diluted Great Salt Lake water all died within days after introduction. No feeding was observed by any of the animals during the experimental period. An unusual arrhythmic contraction of the appendages of the crabs was noted after three days of exposure to the mixture.

Experiment II.— The four American lobsters reared in altered Great Salt Lake water all survived for 45 days. The lobsters died pe-

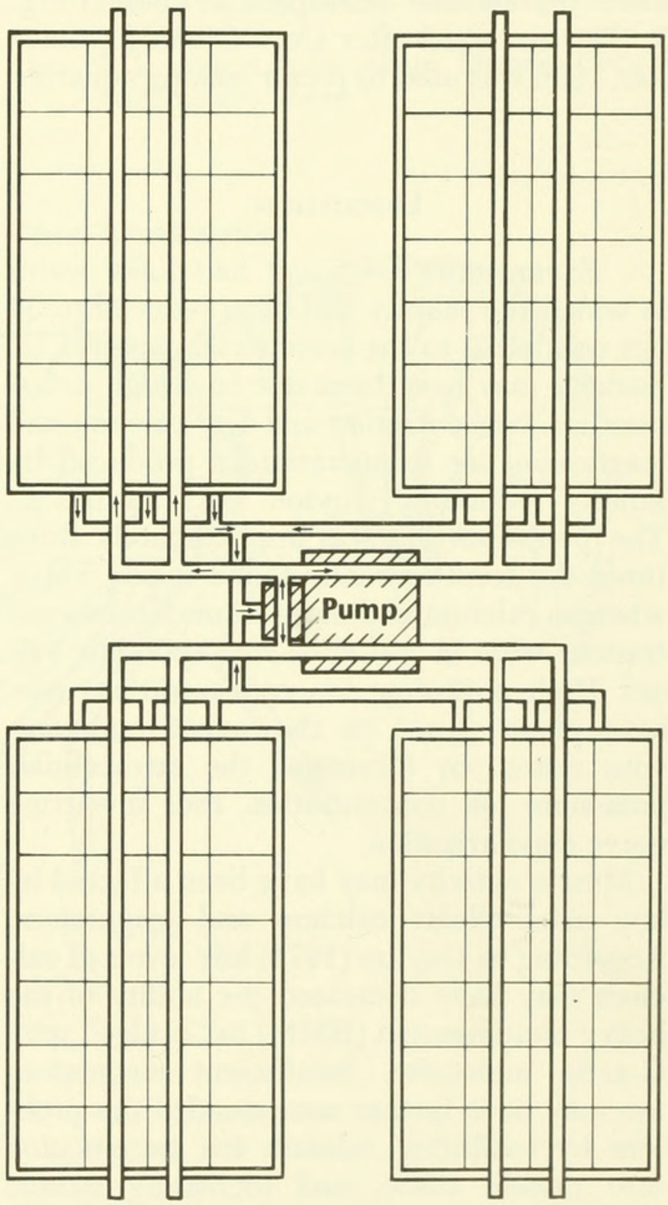

Fig. 4. Experimental aquaria system showing four tanks interconnected by a single pump.

riodically after the initial 45 days, with one animal surviving for 97 days in the altered Great Salt Lake water.

All animals manifested similar symptoms before death, which included self-induced amputation of one or both of the large front claws, and a light blue exoskeleton which became soft and flexible.

EXPERIMENT III.— Lobsters maintained in artificial sea water prepared from Instant Ocean displayed 16 percent more growth than those lobsters reared in altered Great Salt Lake water (Table 3).

Results of water quality analysis are presented in Table 4. These data indicate that water quality during the experiments was acceptable for lobster maintenance.

Mortality occurred in both water types when the animals attempted to moult (Fig. 5). This occurred after Dow Corning primer coat 1206 was used to repair leaking aquaria.

DISCUSSION

EXPERIMENT I.— Great Salt Lake water in which the salinity had been reduced to 34 ppt was lethal to the hermit crab *Pagurus sp.* Toxicity may have been due to a high potassium ion concentration and low calcium and magnesium ion concentrations produced by salinity reduction (Guyton 1971) (Table 2). The potassium ion was approximately three times the level normally found in sea water, whereas calcium and magnesium ion concentrations were ½ and ⅓ of corresponding values. High potassium ion concentrations may have placed stress on the invertebrate nervous system by increasing the extracellular potassium ion concentration, thus thwarting nerve depolarization.

Muscle activity may have been affected by low extracellular calcium and magnesium. According to Guyton (1971) low levels of calcium may have decreased the ability of the heavy meromyosion (HMM) to "bridge" with G-actin molecules. Insufficient magnesium ion may have further compounded the problem by inhibiting calcium ion transmission into muscle tissue, and increasing muscle contraction and irritability (Guthrie 1975).

Nervous and muscular interference due to ionic imbalances may have been demonstrated by the frequent sporadic flexure of the appendages by the crabs.

EXPERIMENT II.— Alteration of Great Salt Lake water by freshwater dilution and dry chemical addition produced a medium which supported the American Lobster for short periods of time. However, the death of the animals between 45 and 90 days suggests that the medium and the physical conditions were far from adequate. Loss of the large anterior claws, slow moulting, and soft flexible exoskeletons also suggest that diet, and/or physical environment, contributed to the degenerative condition of the experimental lobsters.

EXPERIMENT III.— The average increase in carapace length for lobsters grown in altered Great Salt Lake water was 29.75 percent, but was 46.0 percent for those grown in Instant Ocean. Statistical analysis of each group showed no significant difference between individual tanks of each type of water, but a highly significant difference between water types at the 0.05 confidence level. Average water quality parameters for both types of

TABLE 3. Average carapace lengths for 28 lobsters per tank cultured in Instant Ocean and altered Great Salt Lake water for a 60-day period.

Tank	Beginning lengths mm	Finishing lengths mm	% increase
Instant Ocean			
1	6.56	9.49	44
2	6.61	9.53	44
3	6.34	9.55	50
4	6.45	9.47	46
Altered Great Salt Lake water			
1	6.07	7.89	29
2	5.78	7.81	35
3	5.37	7.11	32
4	6.24	7.68	23

TABLE 4. Average water quality data for Instant Ocean and altered Great Salt Lake water for the 60-day experimental period.

Measurement	Instant Ocean	Great Salt Lake
Dissolved oxygen	6.95 ppm	7.09 ppm
Salinity	33.06 ppt	33.85 ppt
pH	7.9	7.9
Temperature	21.9 C	21.7 C
Nitrite	0.0 ppm	0.0 ppm

water were within the acceptable ranges proposed by Spotte (1970) and Hughes, Sullivan, ans Shleser (1972).

Survival data for animals held in each water type was not useful because of sudden mortality in both water systems which occurred after the repair of leaks with Dow Corning 1206 primer coat. Although the plastic primer had serious affects on some lobsters, others appeared to be unaffected and continued to feed and grow normally. Most of the lobsters were found dead in a partially moulted condition. The cause for death during this process may have been due to asphyxiation caused by the old shell pinching the new softer shell over the gills, thus inhibiting water flow. Those animals which moulted successfully did not die immediately, but wasted away for several months. In some cases the old shell was shed successfully except for the walking legs, claws, or tail. These animals frequently became cripples because the new shell hardened in odd shapes and positions. Animals which had undergone incomplete ecdysis displayed normal responses to food and seemed to eat normally. In some cases these animals lived for comparatively long periods of time and moulted as many as three times. In no case, however, did the animals ever regenerate a normal shell.

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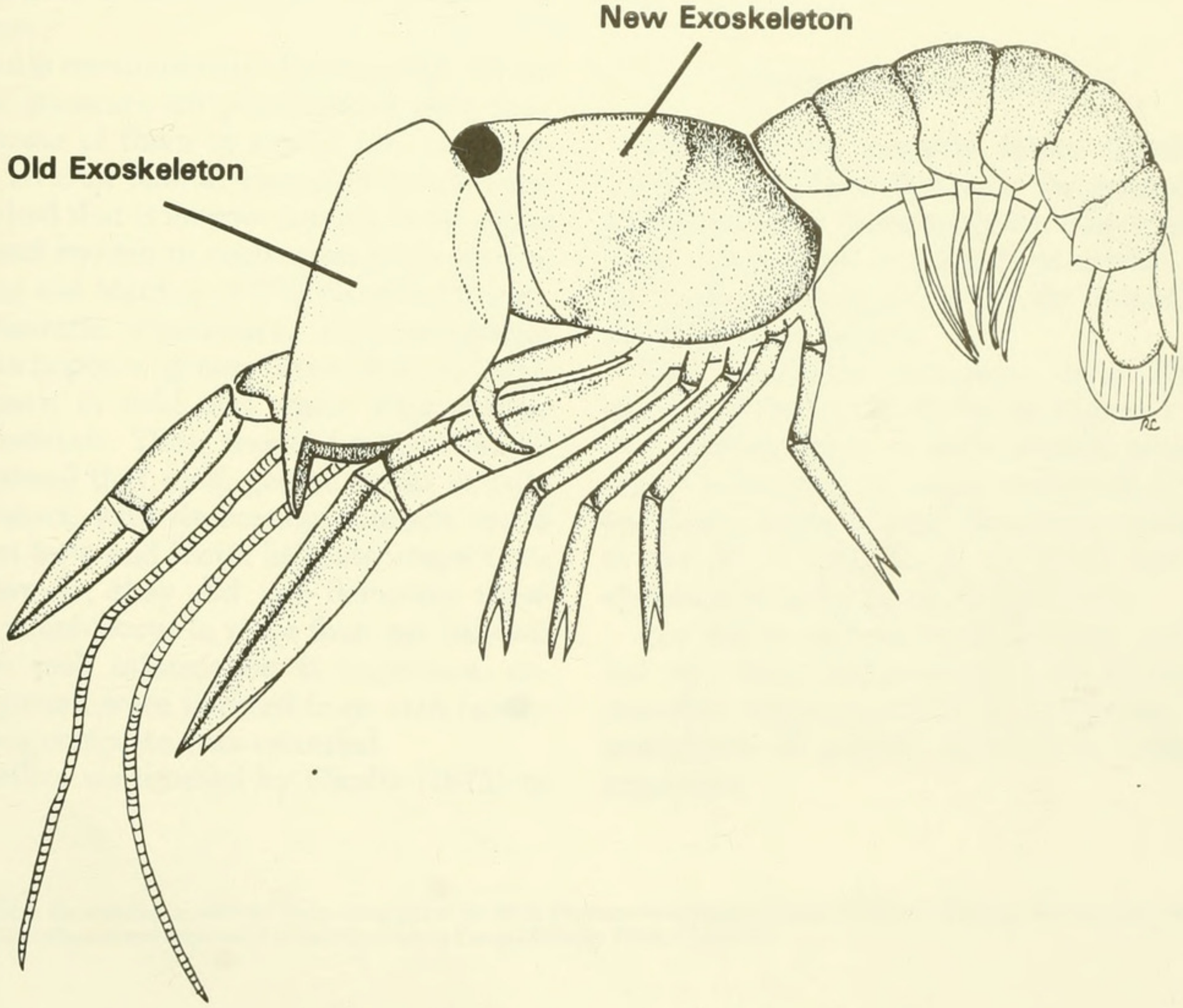

Fig. 5. Artist's drawing of lobsters experiencing incomplete moulting syndrome.

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