Neves

RICHARD J. NEVES

Imlay 1973

MALACOLOGIA, 1973, 12(1): 97-113

EFFECTS OF POTASSIUM ON SURVIVAL AND DISTRIBUTION OF FRESHWATER MUSSELS

Marc J. Imlay
United States Environmental Protection Agency
National Water Quality Laboratory
6201 Congdon Boulevard
Duluth, Minnesota 55804, U.S.A.

ABSTRACT

1. In the laboratory potassium ions were lethal to 4 species of freshwater mussels. Eleven ppm K was lethal to 90% of *Actinonaias carinata*, *Lampsilis radiata siliquoidea*, and *Fusconaia flava* in 36-52 days of exposure, and 7 ppm K was fatal to the latter 2 species in about 8 months. *Amblema plicata* was almost as sensitive as the other species. Similar K ion concentrations occur naturally in many North American rivers.

2. On the basis of National Water Quality Network data on potassium concentrations and the concentrations lethal to mussels in the laboratory, it was predicted that certain rivers would not have mussels and others would. Known distribution of mussels was generally correlated with the predicted locations. In 1 study the 6 rivers with more than 7 ppm K were not reported to have mussels. Mussels were reported from 28 of 39 rivers with less than 4 ppm K but from only 2 out of 10 rivers with 4-7 ppm K.

3. On the basis of the laboratory and field data, the predicted maximum safe level for the continued existence of most freshwater mussels is 4-10 ppm potassium. It is recommended that the concentration of potassium not be allowed to increase in mussel producing rivers if the concentration is above 4 ppm.

INTRODUCTION

This investigation owes its origin to the observation by Koshtoyants & Salánki (1958) that addition of KCl to produce a dissolved potassium ion concentration of 10^{-3}M (39 ppm) exceedingly altered the "daily activity pattern" of the freshwater mussel, *Anodonta cygnea* (Linnaeus) (Unionidae: Anodontinae)[1], and by the knowledge that this concentration was not much greater than that found in some rivers. Although mortality of *A. cygnea* was not reported, the exposures were for only about 1 week, and thus it was possible that longer exposures at lower concentrations would be lethal to these mussels. Ellis, Merrick & Ellis (1931) studied the effect of potassium on freshwater mussels but only at concentrations of 0.1% KCl or more. The purpose of the present investigation was to study the possibility that potassium at concentrations found in some rivers was lethal to North American mussels. These are rapidly dwindling in numbers [according to Stansbery (1970) at least 8 species have recently become extinct because of Man's activities], and have considerable commercial importance (Neel & Allen, 1964; Lopinot, 1967; Isom, 1969).

MATERIALS AND METHODS

A preliminary exposure of mussels to about 30 ppm potassium and a 2nd exposure to about 9 ppm potassium were conducted in order to yield a preliminary indication of the toxic concentrations of potassium. Two more experiments followed each with 4-5 concentrations and a control.

Testing apparatus

The testing apparatus was effectively the same in all the experiments and will be described only for the 1st experiment. There was a flow of fresh water con-

[1]The normal active phase lasted 50-100 hours and the rest phase 5-15 hours but after potassium addition both phases were 3-5 hours.

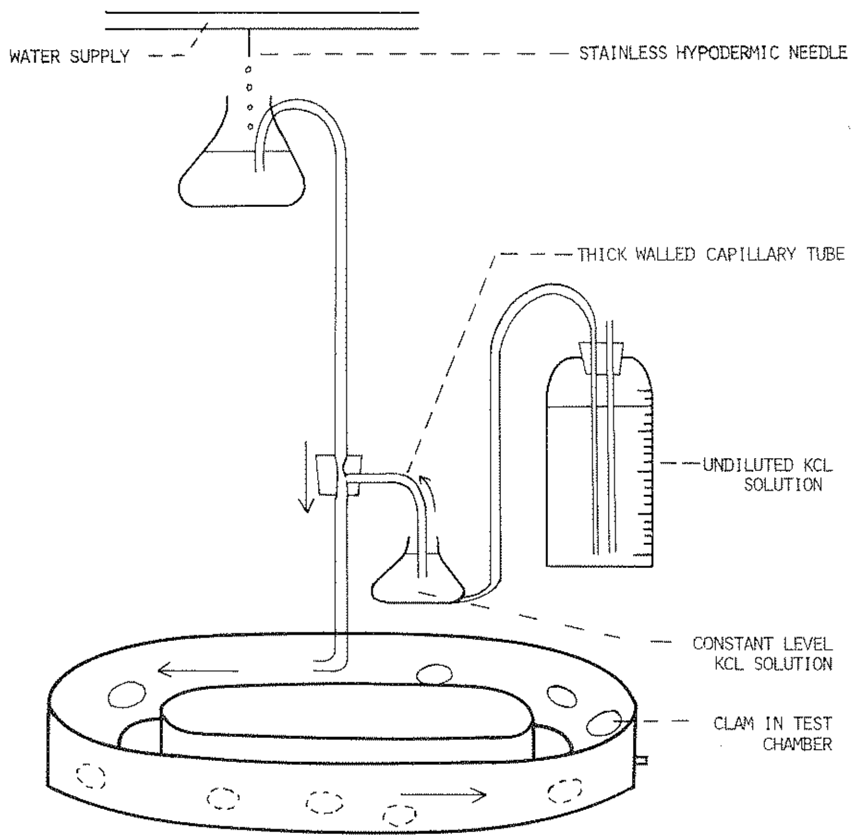


FIG. 1. Potassium toxicity testing apparatus.

taining a constant concentration of potassium into the test chamber. A 20 liter stainless steel chamber contained the test animals and received 1.0 liter of the test water at regular (52.5-56.1 min.) intervals. This interrupted flow was obtained by first directing water into a liter flask which emptied about hourly upon filling to the level of a siphon tube (Fig. 1). As the water passed down a tygon tube towards the experimental chamber it received a precise aliquot of prepared highly concentrated KCl solution through a capillary tube because of the venturi effect. Daily measurements of the volume of highly concentrated KCl solution removed were used to calculate the actual diluted concentration in the testing chamber.

The potassium ion concentration ranged between 24.4 ppm and 34.4 ppm ($\bar{x}=30.1$ ppm). The concentration in the 2nd experiment was held at about 9 ppm. This calculated concentration was verified on 2 occasions by the colorimetric method as detailed in *Standard Methods for the Examination of Water and Waste Water* (cf. Anonymous, 1967: 240-242). The measurements were 9.65 ppm and 8.85 ppm.

For the final experiments the calculated potassium ion concentration was verified throughout each experiment's duration by the flame emission method on 4-5 day composite samples of water from the testing chambers. Table 1 shows the mean flame emission concentrations as well as the range (highest and lowest measured values). The daily calculated concentrations were close to the flame emission composite averages. Note the low potassium concentration in untreated

TABLE 1. Water qualities present in the 3rd and 4th experiments on KC1 toxicity.

Third experiment (December 19, 1968-January 25, 1969)						
	Potassium flame emission concentration (ppm)					
Mean:	57	35	24	15	11	1 (control)
Range:	54.0-60.8	32.5-36.4	22.3-25.0	13.8-15.8	9.9-12.4	0.8-1.0
Water introduced per hour (liters)	2.7	2.7	2.4	2.7	2.6	1.9
Illumination (foot candles)	22	22	21	22	19	16
Velocity of water current (feet per second)	0.20	0.20	0.20	0.14	0.11	0.20
pH (January 2)	7.5	7.5	7.5	7.5	7.5	7.5
Fourth experiment (July 14, 1969-May 14, 1970)						
		Potassium flame emission concentration (ppm)				
Mean:		57	37	11	7	1
Range:		47-70	36.3-38.4	9.7-11.9	5.5-8.2	0.5-1.1
Water introduced per hour (liters)		6.9	4.9	5.6	5.5	4.0
Illumination (foot candles)		22	22	22	19	16

(control) test water.

Collection and handling of animals

Three- to six-inch *Amblema plicata* (Say), *Lampsilis radiata siliquoidea* (Barnes), *Actinonaias carinata* (Barnes), *Lampsilis ovata ventricosa* (Barnes), and *Fusconaia flava* (Rafinesque) were chosen as test species for 2 reasons. They belong to the clam harvester's commercial 3 ridge, mucket, pocketbook, and pigtoe forms respectively (Lopinot, 1967). Secondly, they were collected from local rivers having a calcium content that was analysed and found to be at most 20% greater than that of the laboratory test water (described under "test conditions") of 13.5-13.7 ppm. This small difference minimized calcium content, a major constituent of mollusks, as a difference between natural and test water. *Amblema plicata* is known also as *Amblema costata* Rafinesque or *Crenodonta costata* (Rafinesque), and *Actinonaias carinata* as *Actinonaias ligamentina* (Lamarck).

For the 1st experiment, 17 mussels were collected in November 1967 from the Eau Claire and St. Croix Rivers, Wisconsin, and maintained at 10-12° C and 5-5.5 ppm dissolved oxygen until testing which began on January 28, 1968. These included 4 *Lampsilis radiata siliquoidea*, 4 *Lampsilis ovata ventricosa*, 8 *Fusconaia flava*, and 1 *Amblema plicata*. For the 2nd experiment 8 *Lampsilis radiata siliquoidea*, 9 *Lampsilis ovata ventricosa*, and 6 *Fusconaia flava* were collected from the Eau Claire River and held at 5° C and saturated dissolved oxygen until testing began about 2 weeks later, on April 7, 1968. Specimens of these species from the collection sites on the St. Croix and Eau Claire Rivers were identified by Dr. Henry van der Schalie.

For the 3rd experiment each of 6 testing chambers received 10 *Actinonaias carinata* on December 11, 1968. Almost all of these animals were from collections of equal numbers made on October 28 and December 6 from Yellow River, Wisconsin, a few miles above the St. Croix River. However another collection of what was believed to be the same species from the Yellow River was identified by Dr. David Stansbery as containing about 33% *Lampsilis radiata siliquoidea*. He remarked (pers. comm.) that "The Yellow River material was most interesting since the *Lampsilis radiata luteola* (Lamarck, 1819) (=*siliquoidea* Barnes, 1823) are so very similar in shell characters to the *Actinonaias ligamentina* (Lamarck, 1819) (=*carinata* Barnes, 1823) from the same site." Both species are members of the unionid subfamily Lampsilinae, but there was no way of knowing which specimens of each had been included in the experiment. However, the absence of any bimodality in the results makes this experiment usable. *Amblema plicata* was collected from Moose River, Minnesota, near the city of Sturgeon Lake, on November 25 and 27. The clams were maintained in water saturated with oxygen at about 10° C until testing (potassium was introduced on December 19). There were not enough *Amblema plicata* for 10 specimens per testing chamber since ice cover prevented sufficient collecting; each chamber received only 8 or 9 *Amblema plicata*.

Lampsilis radiata siliquoidea and *Fusconaia flava* were used for the 4th experiment. Ten mussels of each species per test concentration were collected from Ox Creek, Wisconsin (uppermost tributary of St. Croix River) on July 14, 1969, and exposure to potassium began the same day. Conditions at Ox Creek were potassium, 0.4 ppm; temperature, 28.4°C (19°C on July 10); alkalinity, 58 ppm; total hardness, 58 ppm; calcium, 15.6 ppm; and magnesium, 4.3 ppm.

The exposure extended for over 300 days and the mussels were fed 1 gram of trout fry commercial feed per test chamber twice daily. No successful report for rearing mussels (other than glochidia) in the laboratory was found in the literature, although Florkin (1938) studied adult mussels of *Anodonta cygnea* in running tap water without nourishment for 22 months before the mussels succumbed.

The mussels in the 3rd and 4th experiments were examined daily for mortality, and mussels with gaping valves which remained open after an attempt was made to close them by hand were considered dead. For uniformity among the tests at each potassium concentration, each testing chamber received 1 mussel from each of 10 size categories.

Testing conditions

Laboratory conditions of temperature, pH, *etc.*, similar to those in natural conditions, were maintained satisfactorily for the well-being of the animals. Except for the 4th experiment which utilized untreated water pumped directly to the laboratory from Lake Superior, the test water was Lake Superior city water dechlorinated with carbon filters.

In order to provide lighting similar to natural conditions, combined fluorescent (Durotest[2] optima FS) and incandescent illumination were used; photoperiod was automatically adjusted to the local (Duluth) conditions. Foot candles of illumination at the water surface for the final experiments are shown in Table 1.

In the 1st experiment (Fig. 1), mixing in the test chamber was adequate because the water entered parallel to the channel of the ellipsoid tank at a high velocity. In the 2nd experiment, rotating paddle wheels provided a continuous current of 1 ft/7 sec.

Electrical stainless steel stirrers set obliquely in each ellipsoid chamber in the 3rd and 4th experiments provided the flow

[2]Mention of commercial products does not constitute endorsement by the United States Environmental Protection Agency.

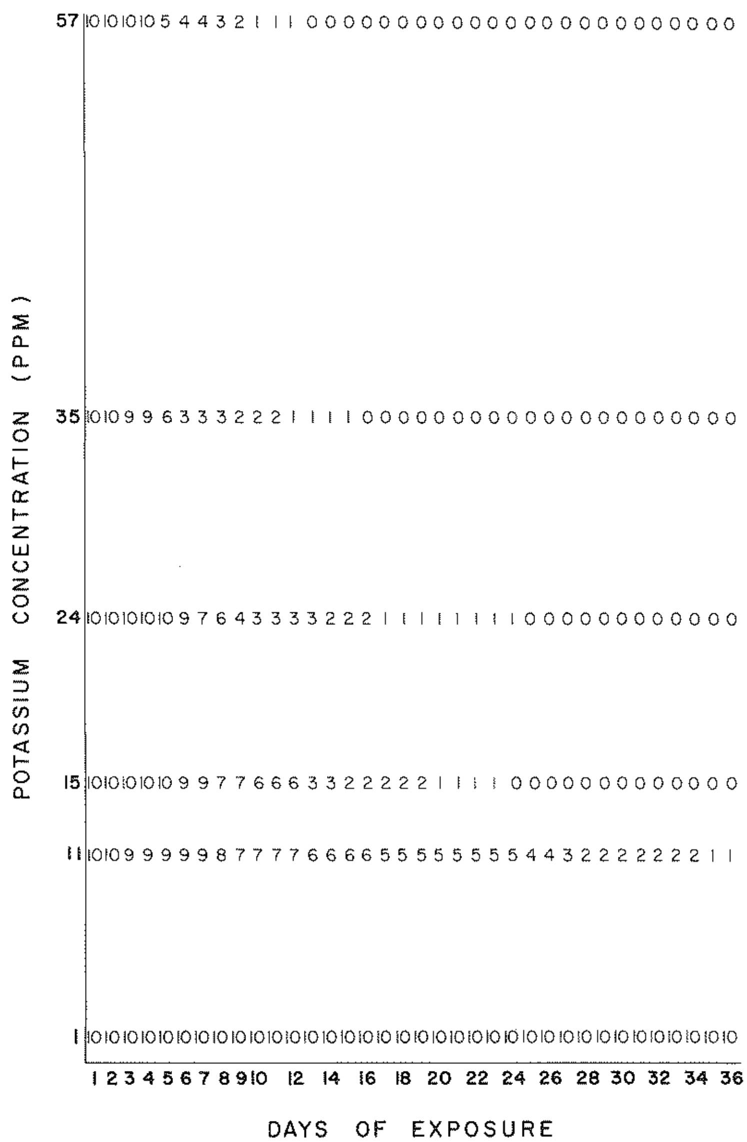


FIG. 2. Number of live mussels *(Actinonaias carinata)* during exposure to potassium.

rates shown in Table 1; these rates simulate stream conditions. Table 1 shows the amount of water entering each test chamber per hour in the 3rd and 4th experiments. The total volume of a test chamber was 32.5 liters. From this information one can calculate turnover rates, if desired.

pH readings taken on January 2 in the 3rd experiment are shown in Table 1. In the 4th experiment, pH was measured weekly in all chambers and varied from 7.0-7.7.

Temperature was measured several times a week in all chambers and in the 1st experiment ranged from 11-13°C, in the 2nd experiment from 14-18°C, in the 3rd experiment from 18-19°C and in the 4th experiment from 16-21°C.

Dissolved oxygen was measured once weekly in all test chambers with the azide modification of the Winkler method; measurements were also made each time

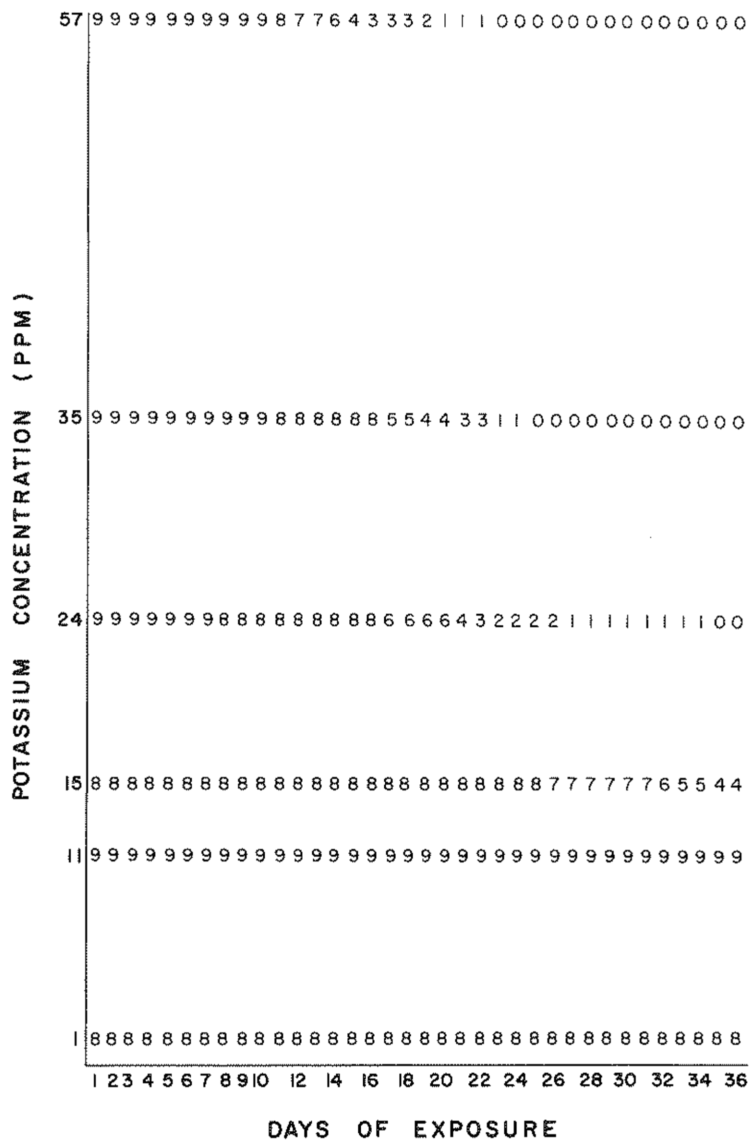


FIG. 3. Number of live mussels *(Amblema plicata)* during exposure to potassium.

more than one mussel died.

Dissolved oxygen, with one exception (1 ppm 2 days in highest concentration of potassium of 3rd experiment), was always much greater than that found to be required for these species of mussels in concurrent experiments and ranged from 4.5-9.6 ppm.

In the 4th experiment total hardness, calcium hardness, acidity (as mg/l $CaCO^3$, Anonymous, 1967) and alkalinity were measured in all test chambers and varied from 45-51.5 ppm, 34-40 ppm, 1-2 ppm, and 43.5-45 ppm $CaCO^3$, respectively.

RESULTS

None of the mussels in the 1st experiment (about 30 ppm potassium) died in the first 17 days of exposure, but more than half died one by one in the next 15 days. Those which died were 4 *Lampsilis*

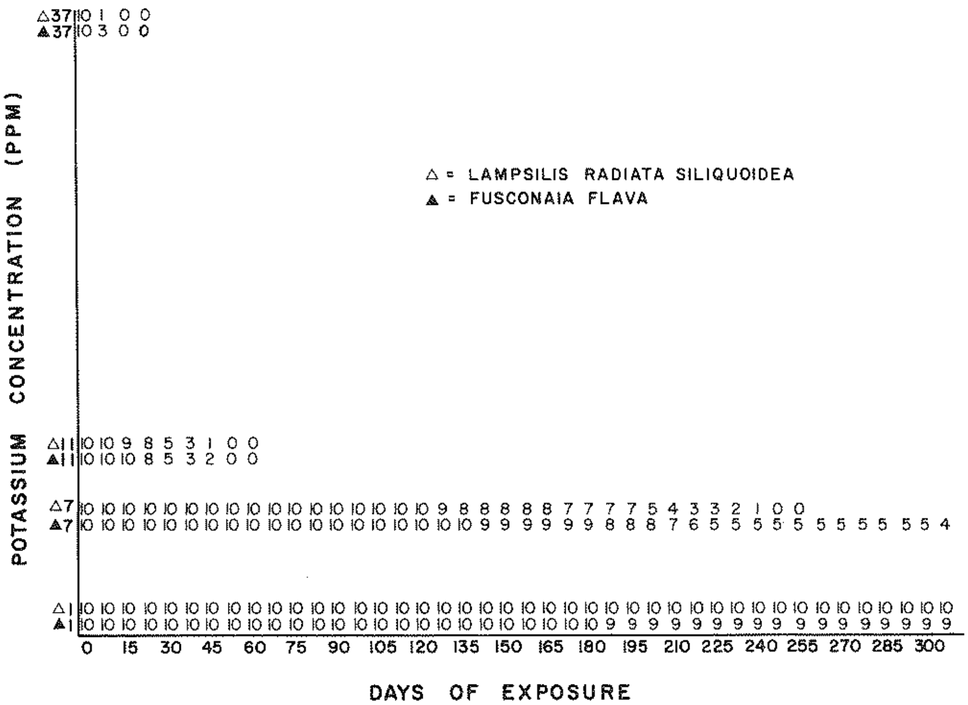


FIG. 4. Number of live mussels (*Lampsilis radiata siliquoidea* and *Fusconaia flava*) during exposure to potassium.

out of the initial 8 animals, and 5 *Fusconaia flava* out of the initial 8.

In the 2nd experiment (about 9 ppm potassium), 56 days of exposure brought the death of 6 mussels while 16 mussels died in the next 31 days of exposure.

Figs. 2, 3, and 4 show the number of days of exposure required to kill specimens of each species at each potassium concentration in the 3rd and 4th experiments. Eleven ppm was lethal to 90% of *Actinonaias carinata* in 36 days (Fig. 2). *Amblema plicata* was not quite as sensitive (Fig. 3). In 36 days 50% had died in 15 ppm K. *Lampsilis radiata siliquoidea* and *Fusconaia flava* were tested at lower concentrations and died in about 8 months at 7 ppm K (Fig. 4). Mortality was much more rapid at 11 ppm. Only 1 of the 40 control animals died while the test animals were undergoing exposure. Further, on March 26, 2 months after the last day of exposure to potassium in the 3rd experiment, only 1 of the 20 control animals had died. Conditions for the 2 months remained the same as during exposure (same temperature, oxygen, retention time, etc.), and consequently it is evident that the control animals had been in healthy condition during exposure.

In conclusion 2 species of the amblemid subfamily Ambleminae (*Amblema plicata* and *Fusconaia flava*) and 2 species of the unionid subfamily Lampsilinae (*Lampsilis radiata siliquoidea* and *Actinonaias carinata*) are mortally sensitive to very low levels of potassium.

DISCUSSION

Toxicity and distribution

The laboratory experiments demonstrated that the 4 species tested from 2 of the 3 subfamilies of unionid clams were killed by concentrations of potassium lower than those found in some rivers of the United States (cf. National Water

Quality Network, 1962). K^+ (11 ppm) killed 90% of *Lampsilis radiata siliquoidea* and *Actinonaias carinata* in 36-45 days. Eleven ppm was about as lethal to *Fusconaia flava*. From the rate of change of minimum lethal concentration with time it can be expected that with longer exposures, lower concentrations would produce mortality. The chronic test at 7 ppm destroyed laboratory populations of *Fusconaia flava* and *Lampsilis radiata siliquoidea* in about 8 months. Furthermore, most studies of clams and other animals show that reproduction and/or growth are prevented at sublethal concentrations of various toxicants. Inhibition of spawning in fathead minnows (Mount, 1968) by copper, and reduced growth of clam and oyster larvae (Hidu, 1965) by detergent, are examples. Reproduction, survival, and growth are, of course, all necessary for the ultimate existence of a species. There is evidence that glochidial larvae of *Anodonta* may be more sensitive than adults to KCl. Lábos & Salánki (1963) found the glochidia to respond by abnormal activity to concentrations as low as 10^{-4}M KCl (3.91 ppm K) and sometimes even lower. Thus it is possible that 3.91 or about 4 ppm K^+ is a maximum safe concentration, and only rivers with less than 4 ppm K^+ would contain mussels. The National Water Quality Network (1962) has measured potassium from many rivers in the U.S.A., and on the basis of the Lábos & Salánki report, the acute results at 11 ppm with rate of change described above, and the chronic results at 7 ppm, I hypothetically predicted that the rivers with less than 4 ppm K^+ would generally have mussels, and 7 ppm K was postulated as a predictive indicator that a river would have no mussels. In addition, 4-7 ppm was considered marginal. Since the Network data were tabulated for 3-month composites of weekly samples it

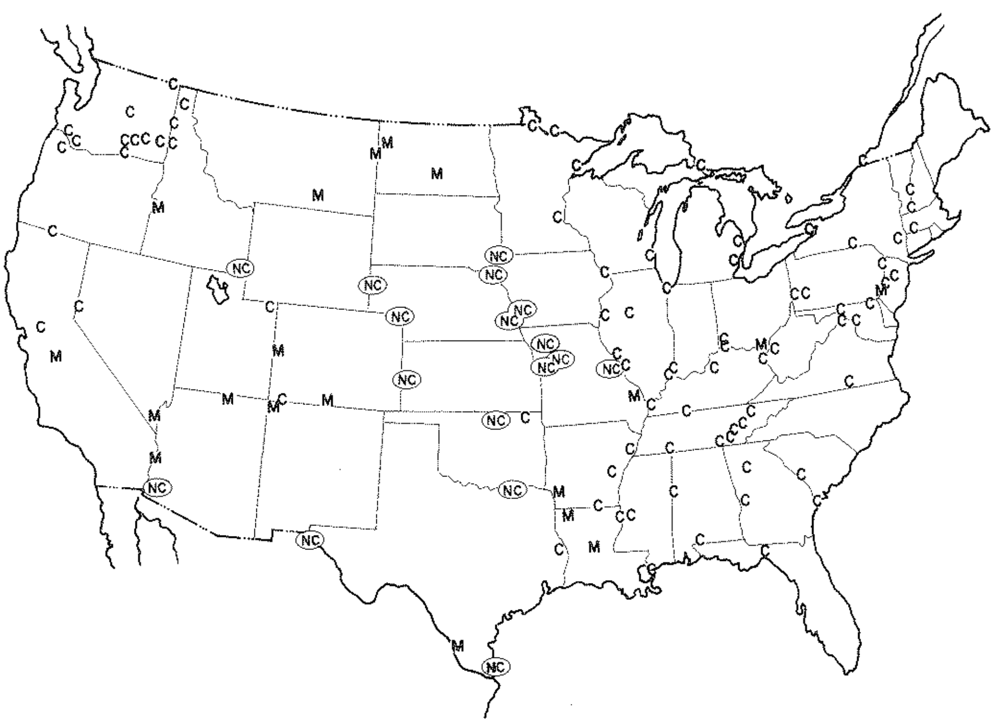
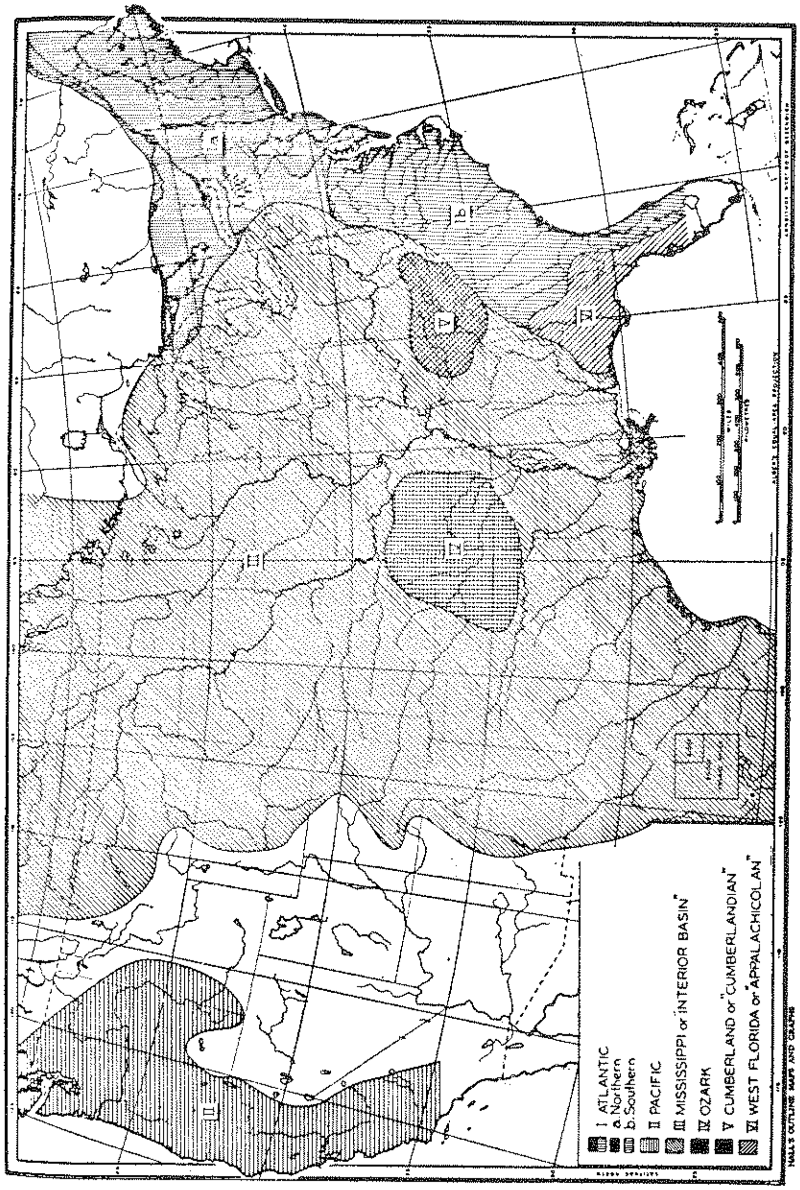


FIG. 5. Prediction of presence of unionid clams (C) (0-4 ppm K), marginal (M) (4-7 ppm K), and no clams (NC) (7 or more ppm K) based upon National Water Quality Network data of potassium measurements.

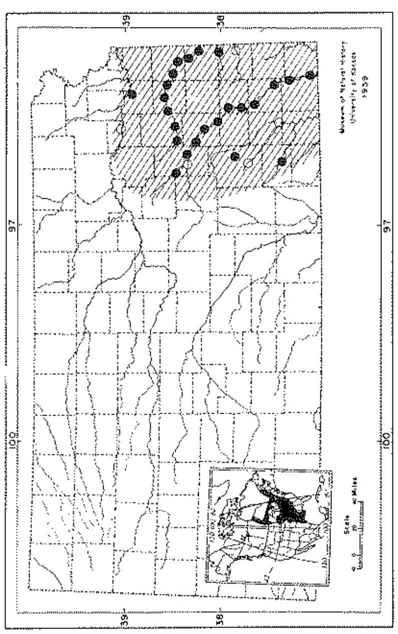


The relatively large area in the United States inhabited by the Mississippi or "Interior Basin" fauna as compared to other distinctive mussel assemblages.

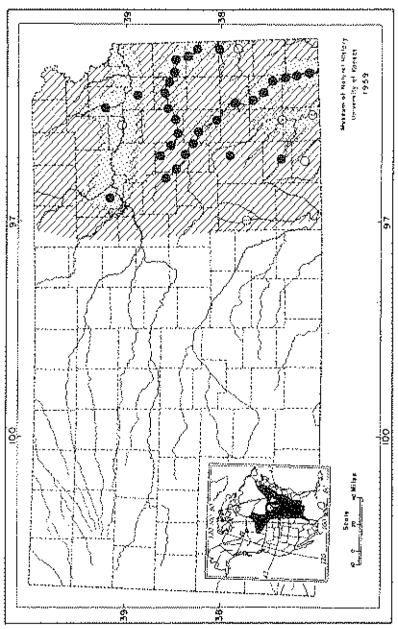
FIG. 6. Reproduction of map published by H. & A. van der Schalie (1950) showing regions of U.S.A. containing unionid clams.

was felt that any high 3-month value would be the effective one regardless of the concentration at another season, and accordingly the higher value was chosen where more than one value was presented. After making these predictions, I plotted the Network data as shown in Fig. 5. The symbols C (less than 4 ppm), M (4-7 ppm), and NC (greater than 7 ppm) are predictions of clams, marginal, and no clams. The symbols are plotted at the specific sites on the river specified in the Network data. Comparison of Fig. 5 with a map published by H. & A. van der Schalie (1950), Fig. 6, shows a partial correspondence of high potassium concentrations with the regions of the U.S.A. that are known to essentially not contain mussels.

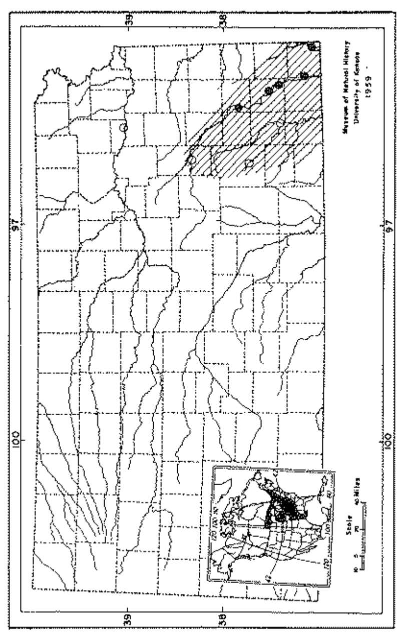
The only discrepancy between Figs. 5 and 6 is the North Dakota to Texas zone of the U.S.A. But the occurrence of *Fusconaia flava, Amblema plicata, Ac-*



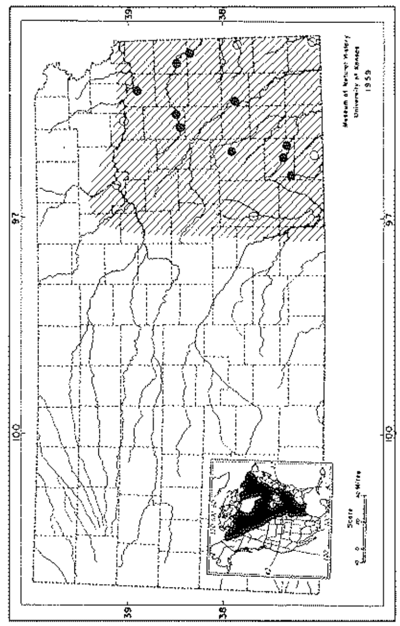
Distribution of *Fusconaia flava* in Kansas. Insert map shows approximate distribution of this species in North America.



Distribution of *Crenodonta peruviana peruviana* (dots) and *C. p. costata* (lines) in Kansas. Areas of intergradation are indicated by overlap of lines and dots. Insert map shows approximate distribution for both subspecies in North America.



Distribution of *Actinonaias carinata carinata* in Kansas. Insert map shows approximate distribution of this species in North America.



Distribution of *Lampsilis radiata siliquoidea* in Kansas. Insert map shows approximate distribution of this subspecies in North America.

FIG. 7. Reproduction of maps published by Murray and Leonard (1962) showing essential absence of unionid clams from North Dakota to Texas. For a more up-to-date survey of distributions within the Canadian Basin, the reader is advised to see Clarke (1972).

tinonaias carinata, and *Lampsilis radiata siliquoidea* (cf. Murray & Leonard, 1962; 41, 48-49, 110 and 151, respectively), species tested in the present studies in the laboratory, as well as the occurrence of the numerous other species of the Midwest is limited in significant numbers to only the eastern fringe of the North Dakota to Texas zone (Fig. 7). Van der Schalie (pers. comm.) also notes[3] that the mussels found in this zone are few in number; they were presented on his map (Fig. 6) to show that the relatively few mussels which *are* found here belong to the Mississippi basin assemblage.

A 2nd method of testing the hypothesis was to compare the Network data with information on the presence or absence of mussels in the Network rivers, some of which have been sampled for mussels by the Ohio State Museum (Stansbery, pers. comm., 1969). None of the 6 streams containing more than 7 ppm K (Colorado at Yuma, Bear, Big Sioux, North Platte, Platte, and South Platte) was recognized by Dr. Stansbery to be reported in the literature as having mussels. Personnel from the Ohio State Museum have sampled one of these rivers (the Colorado River at the Network Yuma site) and found no mussels. Of the streams with less than 4 ppm K, Dr. Stansbery was unsure of 2 rivers but for the others, 28 of 39 were known to have mussels from reports in the literature or from Ohio State Museum sampling. In the marginal category (4-7 ppm K), only 2 of the 10 rivers were known to have mussels. For the sake of unbiased interpretation it should be noted that these 2 rivers were the only 2 sampled by Ohio State Museum. The 10 rivers had no known literature report of mussels. It should be noted that 28 of 39 is significantly different from 0 of 6, $p < 0.001$, or 2 of 10, $p < 0.003$ (Croxton & Cowden, 1955: 679-680).

An interesting case of mussel distribution was described by Cvancara (1966) for the Red River of the North and its tributaries. Information on potassium levels in many of these tributaries appears in Water Resources Data for North Dakota (1966, 1968, and as yet unpublished data kindly supplied by the Geological Survey at Bismarck, North Dakota and Lincoln, Nebraska) and in Water Resources Data for Minnesota (1965, 1966, 1967, and 1968). Potassium was measured in each tributary close to one of the sites indicated by Cvancara as having mussels. Average values were provided or were otherwise calculated by the author. Several species of mussels were found by Cvancara in the following tributaries in Minnesota: South Branch Two Rivers (4 ppm), Middle River (4), Red Lake River (4), Wild Rice River, Minnesota (5), Buffalo River (7), Pelican River (5-6), Ottertail River (3). In North Dakota the Pembina River had 8 ppm potassium but was similarly rich in mussels. This will have to be tolerated as a slight infringement on the hypothesis that rivers over 7 ppm will not have mussels. The Tongue River (4) in North Dakota had 4 species of mussels. The Forest River, North Dakota, was rich in mussels in the upper reaches near Fordville (4). At Minto (6) mussels were also found. Below this point mussels were not found, but Cvancara (1966) reports that the chloride level became very high. Suggestive evidence that potassium was also high will be mentioned shortly.

Finally, the Sheyenne River, North Dakota, was rich in mussels throughout the sampled region (lower part). At the lowest points, West Fargo and Harwood, potassium was 8 ppm. Samples taken slightly

[3]The correlation here is striking and interesting. The basic and widespread "Mississippi" mussel assemblage usually becomes sparse in such western regions as extend from the Dakotas to Texas, particularly because the streams are often too intermittent, or, as in the case of the Missouri drainage, the rivers are often too silted to permit mussel faunas to survive. It should also be emphasized that the mussel distribution patterns as depicted partially reflect the fish distribution because of the host-parasite relations between larval mussels and their fish hosts. In any case the correlation as shown is a remarkable one and indicates biological relationships that warrant further study. Few animals are better suited for studying salt content or mineral relationships than mussels which often remain active for 25 years and monitor the materials taken into the shell in the growth process.

upstream from mussel sites were found to have potassium values of 10 ppm. Thus this river also slightly erodes the predictive hypothesis.

The following rivers were high in potassium and had few or no mussels. The Wild Rice River, North Dakota (15 ppm), had only 1 species and only 1 out of many sampling stations yielded any mussels at all. The Goose River, North Dakota, at Portland (8-14) and at Hillsboro (10-12), was well sampled for both potassium and mussels but had only 1 species.

Cvancara (1966) found that the upper reaches of the Park, Turtle, and Forest Rivers were rich in mussels and had a low chloride content. The lower reaches were devoid of mussels and high in chlorides. He concluded that a correlation "of ecological significance" appeared to exist between high chlorides and absence of mussels. Pollution and physical conditions (bottom type, turbidity, river discharge rate, or industrial and municipal effluent) were believed not to be probable causes. The high chloride content was reported by Cvancara as being brought in by seepage from the Dakota group of cretaceous rocks. Observing that these rocks do contain potassium (Dole & Wesbrook, 1907), it appeared to me that potassium might be high where the chloride was high and be the direct cause of the absence of mussels. The following data on the Park River substantiates this explanation. The South Branch of Park River below Homme Dam (7 ppm) had mussels. Further downstream at Grafton, the Park River proper had no mussels and the potassium had increased (survey the same day) to 12 ppm. Finally, another measurement on that day at Oakwood (still further downstream) showed 40 ppm and there were no mussels.

The correlation of potassium concentration with mussel distribution is not necessarily a direct cause-and-effect correlation, but could conceivably be created by a common variable (carbonate, Mg, silting, etc.) that causes both the potassium and distribution variation. This is not considered likely, however, because of the laboratory demonstration of direct toxicity. Potassium may enter a stream naturally or artificially as a pollutant. Potash ($K^{2}CO^{3}$) production has been listed as a significant and steady component of the minerals industry (Krieger, 1968). KCl occurs in brines from oil wells and other industrial wastes (McKee & Wolf, 1963). It is considered to be a significant component of paper wastes (Powers, Sacks & Holdaway, 1967: Table 1) and occurs in runoff from irrigation diversions or excessively fertilized crops. The Green River, Kentucky, lost most of its former mussel abundance from brine waste in 1958 with the opening of the Greensburg, Kentucky oil field (Williams, 1971).

Other organisms

Low concentrations of potassium may be toxic to other animals but only relatively short-term studies of potassium exposure (1 week) have come to my attention (McKee & Wolf, 1963). Fig. 3 indicates less than 50% mortality for *Amblema plicata* for the first 2 weeks of exposure at any concentration tested. Extrapolation of Fig. 3 indicates the probability of such a delay in toxicitity of potassium for concentrations much higher than those used in the present studies. Thus studies of only 1 week, while abounding in the literature, give little evidence of the chronic effects of potassium.

There is scant evidence that potassium may be highly toxic to other animals. Galun & Kindler (1966) found that the medicinal leech, *Hirudo medicinalis* (Linnaeus), would no longer imbibe an NaCl: glucose solution across a membrance if 7.5×10^{-2}M KCl were added, but this was a rather high K^{+} concentration. Coler, Gunner, & Zuckerman (1967) substituted sodium for potassium in the growth medium used with tubificid oligochaetes because of reports of an effect of potassium on tubificids, but again concentrations were high.

There are indications that high sensitivity to potassium may be unique to unionaceans or at least certain mollusks. In a comparison of numerous phyla, (Prosser

& Brown, 1961: 58-63), *Anodonta* was distinguished by the lowest blood potassium along with the other common cations, except for calcium. During narcosis, *Anodonta* (Bivalvia) and *Lymnaea* (Gastropoda: Pulmonata) increase in weight, and the principal ions become diluted in the blood, except for potassium which is released by cells at an even faster rate than it is diluted (Robertson, 1964: 296). Further studies are necessary to show whether chronic sensitivity to potassium is unique or general among aquatic life. Such studies are underway in this laboratory and the results to date show that a freshwater fish, leech, and snail are at least an order of magnitude less sensitive to chronic potassium exposure than the mussel.

Effects of other ions

Salánki (1962) found the common cations K^+, Na^+, Mg^+, Ca^+ to affect seriously the normal activity of glochidial and adult *Anodonta cygnea*, at concentrations which, relative to the actual concentrations in streams, would be important only for the case of potassium in real river conditions.

Although, it is well known that these other cations may ameliorate the toxic effects of potassium, [sodium for *Artemia* (Stahl, 1967), and calcium for *Tubifex* (Ringer, 1899), to cite representative examples] the potassium was highly concentrated in such studies. There is little reason to conclude that their addition would protect organisms from potassium at the low levels found to be chronically lethal for mussels. Since KCl was the vehicle used to introduce K^+ in the present studies, it is advisable to examine the possibility that Cl^- contributed to the observed toxicity. The report by Ellis (1937: Table 7) suggests that Cl^- is not the toxic ion in KCl because goldfish show no apparent injury after 25 days exposure to the very high concentration of 5,000 ppm NaCl.

Evidence from data related to mussels, that Cl^- is not the toxic ion in KCl, is in the Water Quality Network data (1962) which show chlorides to be much higher in mussel producing streams than in KCl solutions which killed mussels in the laboratory. Examples are the Allegheny (10-46 ppm), Escambia (8-100 ppm), Illinois (9-32, 14-40), Little Miami (9-30), Mississippi (Cape Giradeau, Missouri) (9-21), Ouachita (14-355), Potomac (8-18), St. Lawrence (17-36), Wabash (22-132), and Tombigbee (4-58) Rivers. These are all rivers specifically stated by Dr. Stansbery (pers. comm., 1969) as having mussels.

Another line of evidence is the finding that the threshold of NaCl effect on the activity of *Anodonta cygnea* glochidia was at 100 times greater concentrations than the KCl threshold. Further, the effect of NaCl was short lived (Lábos & Salánki, 1963).[4] The order of threshold concentration (based on molarity) was K<Rb<Cs<Mg<Li<Ca<Na as chlorides, with K^+ being effective at the lowest concentration. Only KCl produced a lasting effect compared to NaCl, $MgCl_2$, and $CaCl^2$ even with very high concentrations of chloride (10^{-1}M NaCl). The equivalent amount of chloride in 10^{-1}M NaCl would be found with KCl solutions that yield 3910 ppm K. Incidently, since sodium has been shown consistently to be about 10 times less toxic than potassium in the many reports of acute toxicity for numerous organisms (McKee & Wolf, 1963), it is possible that attention may usefully be directed to industrial processes where sodium may simply be substituted for potassium.

Mode of toxicity of potassium

The specific mode of toxicity of potassium to fresh-water mussels is not known at the present time. An indication as to mode of toxicity is provided by the demonstration by Salánki (1961) that potassium acts directly upon the receptor

[4]Lithium, cesium, and rubidium incidently, had thresholds far greater than concentrations which might be expected outside the laboratory.

system of *Anodonta cygnea* since lesion of siphonal nerves or their paralysis by cocaine abolished the effects of slight potassium addition on normal activity. He found, furthermore, that the blood potassium level increased with addition of KCl but remained constant at the new level regardless of closed or open phase of activity rhythm. Since the closed phase lasted many hours, the animal cannot rid itself of potassium following any possible shielding of itself from the environment by closing. *Anodontoides ferussacianus* Lea (Unionidae: Anodontinae) can prevent the lowering of pH expected under anaerobic conditions by means of such a shielding method (Biondi, 1928; Kraft, 1928).

Koshtoyants & Salánki (1958) presented evidence that functioning of portions of the Krebs cycle may be related to the effects of potassium, although Lukacsovics & Salánki (1964) found the effect of KCl on activity to be unrelated to tissue respiration. Cholinergic transmission may be related to potassium toxicity (Lábos, *et al.*, 1964).

ACKNOWLEDGEMENTS

I wish to thank Messrs. Edward N. Leonard and Robert W. Andrew for the colorimetric and flame emission measurements of potassium, and Mrs. Barbara J. Halligan for assisting in much of the laboratory work. Permission from Dr. Henry van der Schalie (for Fig. 6) and Dr. Harold Murray (for Fig. 7) to republish their maps is gratefully acknowledged. Identifications of species were made by Dr. van der Schalie, University of Michigan, Ann Arbor, Michigan, and Dr. David Stansbery, Ohio State University, Columbus, Ohio. The classification of mussels used here is that of Clarke & Berg (1959).

LITERATURE CITED

ANONYMOUS, 1967, *Standard Methods for the Examination of Water and Wastewater.* 12th ed. American Public Health Association, Inc., New York. 686 p.

BARNES, D.W., 1823, On the genera *Unio* and *Alasmodonta;* with introductory remarks. *Amer. J. Sci.*, 6: 107-127; 258-280.

BIONDI, R.M., 1928, *The ability of the fresh-water clam* Anodontoides ferrussacianus *Lea to counteract the accumulation of acid wastes produced during anaerobiosis.* Master's thesis, Northwestern University, Evanston, Illinois.

CLARK, A.H., 1972, The freshwater molluscs of the Canadian Interior Basin. MALACOLOGIA. 13:1-509.

CLARKE, A.H., JR. & BERG, C.O., 1959, *The Freshwater Mussels of Central New York—With an Illustrated Key to the Species of Northeastern North America.* New York State College of Agriculture, Cornell University, Ithaca, New York. Memoir 367.

COLER, R., GUNNER, H. & ZUCKERMAN, B., 1967, Selective feeding of tubificids on bacteria. *Nature*, 216: 1143-1144.

CROXTON, F.E. & COWDEN, D.J., 1955, *Applied General Statistics.* 2nd ed. Prentice-Hall, Inc., New York. 843 p.

CVANCARA, A.M., 1966, Mussels of the Red River Valley in North Dakota and Minnesota and their use in deciphering drainage history. *Life, Land and Water,* 40: 187-196.

DE LAMARCK, J.B., 1819, *Histoire Naturelle des Animaux sans Vertebres.* Ed. 1. 5, 1818. Ed. 2. 6, 1835.

DOLE, R.B. & WESBROOK, F.F., 1907, The quality of surface waters in Minnesota. *Water Supply and Irrigation Paper,* No. 193.

ELLIS, M.M., 1937, Detection and measurement of stream pollution. *Bull. U.S. Bur. Fish Wildl. Ser.*, 48: 365-437.

ELLIS, M.M., MERRICK, A.D. & ELLIS, M.D., 1931, The blood of North American fresh-water mussels under normal and adverse conditions. *Bull. U.S. Bur. Fish., 49: 509-542.*

FLORKIN, M., 1938, *Concentration du milieu exterieur et hydration chez un lamellibranche d'eau douce* (Anodonta cygnea L.). *Acad. Roy. Belg. Bull. Cl. Sci.*, Ser. 5, 24: 143-146.

GALUN, R. & KINDLER, S.H., 1966, Chemical specificity of the feeding response in *Hirudo medicinalis* (L.). *Comp. Biochem. Physiol.*, 17: 69-73.

HIDU, H., 1965, Effects of synthetic surfactants on the larvae of clams *(M. mercenaria)* and oysters *(C. virginica). J. Water Pollution Control Federation,* 37: 262-270.

ISOM, B.G., 1969, The mussel resource of the Tennessee River. *Malacologia,* 7: 397-425.

KOSHTOYANTS, CH. & SALANKI, J., 1958, On the physiological principles underlying the periodical activity of *Anodonta*. *Acta Biol.*, 8: 361-366.

KRAFT, F.L., 1928, *The Effect of Oxygen and Food Supply on the Amount and Distribution of Respiratory Enzymes in Fresh-Water Clams.* Master's thesis, Northwestern University, Evanston, Illinois.

KRIEGER, J.H., 1968, Basic minerals. *Chem. Eng. News,* 46:74A-79A.

LABOS, E., SALANKI, J. & KLITYNA, G.R., 1964, The effect of cholinotropic drugs on the rhythmic activity of glochidia of fresh-water mussel *(Anodonta cygnea* L.). *Acta Biol.*, 15(2): 119-128.

LABOS, E. & SALANKI, J., 1963, The effect of alkali metal ions and alkaline earth metal ions on the rhythmic activity of glochidia of the fresh-water mussel *Anodonta cygnea* L. *Ann. Biol. Tihany,* 30: 45-57.

LOPINOT, A.C., 1967, The Illinois Mussel. *Outdoor Ill. Mag.* 6(3).

LUKACSOVICS, F. & SALANKI, J., 1964, Effect of substances influencing tissue respiration and of the temperature on the 0^2 consumption of the gill tissue in *Unio tumidus. Ann. Biol. Tihany,* 31: 55-63.

MCKEE, J.E. & WOLF, H.W., 1963, *Water Quality Criteria.* 2nd ed. Publ. No. 3-A. The Resources Agency of California State Water Quality Control Board, Sacramento, California. 548 p.

MOUNT, D.I., 1968, Chronic toxicity of copper to fathead minnows *(Pimephales promelas,* Rafinesque). *Water Resource,* 2: 215-223.

MURRAY, H.D. & LEONARD, A.B., 1962, *Handbook of Unionid Mussels in Kansas.* University of Kansas, Lawrence, Kansas. 184 p.

NATIONAL WATER QUALITY NETWORK, 1962, Public Health Service Publication 663. U.S. Department Health, Education and Welfare, Washington, D.C. 909 p.

NEEL, J.K. & ALLEN, W.R., 1964, The mussel fauna of the Upper Cumberland Basin before its impoundment. *Malacologia,* 1: 427-459.

POWERS, T.J., III, SACKS, R.B. & HOLDAWAY, J.L., 1967, *National Industrial Wastewater Assessment Manufacturing Year 1963.* U.S. Department of the Interior, Federal Water Pollution Control Administration, Cincinnati, Ohio.

PROSSER, C.L. & BROWN, F.A., 1961, *Comparative Animal Physiology.* 2nd ed. W.B. Saunders Co., Philadelphia. 688 p.

RINGER, S., 1899, The action of distilled water on *Tubifex. J. Physiol.*, 22: 14.

ROBERTSON, J.D., 1964, Osmotic and ionic regulation *In:* Wilbur, K.M., and C.M. Yonge (eds.). *Physiology of Mollusca,* Vol. I Academic Press, New York. 473 p.

SALANKI, J., 1961, Role of afferentation in the regulation of the slow rhythm in the periodic activity of fresh-water mussels. *Acta Biol.*, 12: 161-167.

SALANKI, J., 1962, Interoceptive stimuli in the regulation of rhythmicity and periodic activity in fresh-water mussels *(Anodonta cygnea* L.). *Acta Biol.*, 12: 243-251.

STAHL, J.B., 1967, The effect of co-occurrence Chaoborus abundance *In: 15th Annual Meeting of the Midwest Benthological Society.* Southern Illinois University, Carbondale, Illinois. April 6-7, 1967.

STANSBERY, D.H., 1970, Eastern Fresh-water mollusks. *In:* Symposium on Rare and Endangered Molluscs of North America. *Malacologia,* 10: 9-22.

VAN DER SCHALIE, H. & A., 1950, The mussels of the Mississippi River. *Amer. midl. Natur.*, 44: 448-466.

WATER RESOURCES DATA FOR MINNESOTA, 1965, 1966, 1967, 1968, U.S. Dept. Interior, Water Resources Division of U.S. Geological Survey.

WATER RESOURCES DATA FOR NORTH DAKOTA, 1966, 1968, U.S. Dept. Interior, Water Resources Division of U.S. Geological Survey.

WILLIAMS, J.C., 1971 *Mussel Fishery Investigations, Tennessee, Ohio, and Green Rivers.* Final Report 4-19-R Kentucky Department of Fish and Wildlife Resources and Murray State University Biological Station, Murray, Kentucky. 107 p.

ZUSAMMENFASSUNG

BEDEUTUNG DER POTTASCHE FÜR LEBEN UND VERBREITUNG VON SÜSSWASSERMUSCHELN

M. J. Imlay

1. Im Laboratorium waren Pottasche-Ionen für 4 Süsswassermuschelarten ein tödliches Gift. Elf Teile pro Million (T.p.M.) K tötete 90% der Arten *Actiononaias carinata*, *Lampsilis radiata siliquoidea* und *Fusconaia flava* innerhalb von 36-52 Tagen und 7 T.p.M. K die beiden letzteren Arten in etwa 8 Monaten. *Amblema plicata* war fast so emfindlich wie die übrigen Arten. Ähnliche Konzentrationen von K-Ionen kommen von Natur in vielen nordamerikanischen Flüssen vor.

2. Auf Grund der Daten des "National Water Quality Network" betr. Pottaschegehalt und der obigen Untersuchungsergebnisse wurde geschlossen, dass gewisse Flüsse Muscheln beherbergen und andere nicht. Die bekannte Verbreitung der Muscheln wurde allgemein mit der vermuteten Verbreitung verglichen. Von 6 Flüssen mit mehr als 7 T.p.M. K werden keine Muscheln angegeben. In 28 von 39 Flüssen mit weniger als 4 T.p.M. K wurden Muscheln gemeldet, aber nur in 2 von 10 Flüssen mit 4-7 T.p.M. K.

3. Die Laboratoriums- und Gelände-Befunde zeigen, dass die meisten Süsswassermuscheln dauernd nur in Gewässen leben können, in denen der Pottaschegehalt nicht über 4-10 T.p.M. steigt. Es wird empfohlen, die Zunahme des Pottaschegehaltes in muschelführenden Flüssen nicht zuzulassen, wenn die Konzentration mehr als 4 T.p.M. beträgt.

H.Z.

RÉSUMÉ

EFFETS DU POTASSIUM SUR LA SURVIE ET LA DISTRIBUTION DES MOULES D'EAU DOUCE

M. J. Imlay

1. Au laboratoire les ions potassium sont léthaux pour 4 espèces de moules d'eau douce. La dose de 7 ppm K a été léthale pour 90% des *Actiononaias carinata*, *Lampsilis radiata siliquoidea* et *Fusconaia flava* après 36-52 jours d'exposition, la dose de 7 ppm K a été fatale aux 2 dernières espèces au bout de 8 mois environ. *Amblema plicata* est presque aussi sensible que les autres espèces. De telles concentrations d'ion K se rencontrent dans les conditions naturelles dans beaucoup de rivières nord-américaines.

2. Sur la base des données en concentrations de potassium de la National Water Quality Network d'une part et des concentrations léthales établies au laboratoire d'autre part, on a pu prévoir que certaines rivières n'auraient pas de moules, tandis que d'autres en auraient. La distribution connue des moules a généralement été en corrélation avec les localisations prévues. Dans une étude sur 6 rivières avec plus de 7 ppm K, aucune n'avait de moules. Des moules furent trouvées dans 28 rivières sur 39, ayant moins de 4 ppm K, mais seulement dans 2 sur 10 rivières ayant 4-7 ppm K.

3. Sur la base des données dans la nature et au laboratoire, le niveau maximum prévu pour le maintien en vie de la plupart des moules d'eau douce est de 4-10 ppm K. Il est recommandé de ne pas laisser s'accroitre la concentration de potassium dans les rivières productrices de moules si cette concentration est inférieure à 4 ppm.

A. L.

EFFECTOS DEL POTASIO EN LA SOBREVIVENCIA Y DISTRIBUCION DE ALMEJAS DE AGUA DULCE

M. J. Imlay

1. El efecto de potasio fué letal para 4 especies de almejas de agua dulce en el laboratorio. Once ppm K fué letal para el 90% de *Actinonanias carinata, Lampsilis radiata siliquoidea* y *Fusconaia flava* expuestas durante 36 a 52 dias, y 7 ppm K fué fatal para los dos ultimas especies en 8 meses. *Amblema plicata* fué casi tan sensitiva como las otras especies. Concentraciones similares de iones K se encuentran naturalmente en muchos ríos de Norte America.

2. En base a los datos de la Red Nacional de Calidad del Agua sobre concentraciones de potasio, y las concentraciones que fueron letales a las almejas en el laboratorio, se pronosticó que ciertos ríos pueden contener almejas y otros nó. La distribución conocida de las almejas, estaba generalmente correlacionada con los locales pronosticados. En un estudio de 6 ríos con más de 7 ppm K no se registraron almejas, pero fueron encontradas en 28 de los 39 ríos con menos de 4 ppm K, pero sólo en 2 fuera de los 10 ríos con 4-7 ppm K.

3. Sobre la base de datos de laboratorio y en la naturaleza, el pronóstico del nivel de seguridad para la existencia contínua de la mayoría de las especies de almejas, es 4-10 ppm potasio. Se recomienda que la concentracion de potasio no se permita aumentar, si la concentración es superior a 4 ppm.

J. J. P.

АБСТРАКТ

ВЛИЯНИЕ КАЛИЯ НА ВЫЖИВАНИЕ И РАСПРОСТРАНЕНИЕ ПРЕСНОВОДНЫХ ДВУСТВОРЧАТЫХ МОЛЛЮСКОВ

М. ДЖ. ИМЛЕЙ

1. В эксперименте ионы калия были летальными для 4 видов пресноводных двустворчатых моллюсков. $11.10^{-4}\%$ К оказались летальными для 90% ***Actinonais carinata, Lampsilis radiata siliquoidea*** и ***Fusconaia flava*** при экспозиции 36-52 дня, а $7.10^{-4}\%$ К вызвали летальный исход у двух последних видов при экспозиции ∽8 месяцев. ***Amblema plicata*** была почти так же чувствительна, как и другие виды. Естественно, что подобные концентрации иона К встречаются во многих северо-американских реках.

2. На основании данных Национальной Организации по Регистрации Качества Воды (**National Water Quality Network**) по концентрации калия и данных по концентрациям, оказавшимся летальными для двустворчатых моллюсков при лабораторных экспериамантах, было предсказано, что в определенных реках **Bivalvia** должны жить, а в других - нет. Распределение двустворчатых моллюсков, имеющее место в действительности, в общем соответствовало предсказанному. В 1 исследовании получены сведения, что в 6 реках с концентрацией К, более, чем $7.10^{-4}\%$, **Bivalvia** не обнаружены. Двустворчатые моллюски найдены в 28 из 39 рек с концентрацией К меньше, чем $4.10^{-4}\%$, но лишь в двух из 10 рек с $4-7.10^{-4}\%$ К.

3. На основании полученных в лаборатории и полевых данных предсказанная максимальная концентрация для продолжительного нормального существования большинства пресноводных двустворчатых моллюсков - $4-10.10^{-4}\%$ К. Высказаны пожелания недопустимости повышения уровня концентрации К в реках, содержащих **Bivalvia**, если концентрация его там выше $4.10^{-4}\%$.

Z.A.F.