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Almost all of the natural lakes of Iowa develop at certain periods throughout the summer and fall months, heavy growths of small floating plant life commonly known as blue-green algae. These tiny, primitive organisms develop rapidly in certain lakes, and often form unsightly, paint-like scums over calm lake surfaces, and particularly along lee shores. Upon decomposition of these heavy scums, or "bloom" as they are commonly termed, terrifically foul, pig-pen odors issue therefrom, making human living conditions in the vicinity intolerable, and limiting to a large degree all aquatic recreation.

In addition to these unwholesome attributes, certain species of blue-green algae occasionally develop poisonous substances that cause almost instant death to birds and mammals that drink water containing these plants. Present evidence indicates that the healthy, living plants are the most poisonous to warm blooded animals. Upon decomposition of large masses of algae, fish are sometimes killed in great numbers as observed by Prescott (1931), and Mackenthum, Herman and Bartsch (1948). Heavy losses of fish have been observed in Iowa on several occasions where heavy blooms caused di-urnal declines of dissolved oxygen, and the algae were not toxic at the time. Our data indicates that only a few species of algae may become toxic, in fact clinical data points to but one, *Anabaena flos-aquae,* although certainly there may be others equally poisonous at times. A very comprehensive summary of the literature by Olson (1951), includes many authentic references showing that toxic algae may include many species and are of world-wide distribution. His clinical and field observations of the effects of toxic algae in the Minnesota lakes closely parallel those of the Iowa waters.

Almost all of the important recreational lakes in Iowa are subject to unsightly blooms of blue-green algae. Included primarily are: Storm, in Buena Vista county, East Okoboji, Silver, Center and Minnewashta lakes in Dickinson County and North Twin Lake in Calhoun County. Several other natural lakes have periodic blooms, but usually in lesser amounts. Red Haw Lake at Chariton, in Lucas County, an artificial impoundment often has blooms as heavy as in any of the natural lakes. Fortunately, the algae problem is

usually of a nuisance nature in most lakes and no serious effects occur. However, with the ever increasing demands for wholesome recreational areas, and especially with the threat of toxic algae to the public health and welfare, corrective measures are unquestionably a distinct need.

This report concerns primarily a summary of observations and studies that have been made in Iowa, where toxic algae have been responsible for important losses of farm and game animals. These have largely been confined to Storm Lake, and around the Okoboji lakes of Dickinson County.

The Storm Lake Algae Problem

Storm Lake has developed huge blooms of blue-green algae every summer within the memory of the oldest residents of the City of Storm Lake, and doubtless long before white men came to the region. From 1926 through 1932, the city treated the lake with copper sulfate to control algae since the lake was then used as a municipal water supply. The State University of Iowa and the State Fish and Game Department (now Conservation Commission) in 1930 and 1931 conducted extensive studies of Storm Lake and the Okoboji Lakes to determine some of the factors responsible for the blooms, and possible means of control, Prescott (1931). The writer assisted in this study. It was determined that high fertility of the Iowa lakes together with other ideal ecological conditions were responsible for the heavy blooms. Prescott recommended the introduction of the gizzard shad (*Dorosoma cepedianum*) as an experiment in natural control, since these fish are primarily plankton feeders. Also, recommendations were made to administer copper sulfate in local concentrations as soon as the algae appeared in the spring. During the summer of 1934, this was tried experimentally and with good results. During these years there were no toxic algae present, although heavy growths of *Aphanizomenon flos-aquae* and *Microcystis aeruginosa* were present.

The first record available on Storm Lake concerning the development of algae poisonous to livestock occurred on August 29, 1948. At this time, a few dogs were apparently killed from drinking water from the lake. Upon examination it was found that the water contained vast quantities of *Anabaena flos-aquae*. At the same time, a large number of fish perished in the region of the heaviest accumulation of the algae. These were mostly buffalo (*Megastomatobus cyprinella*), carp (*Cyprinus carpio*) and bullhead (*Ameiurus melas*). It is believed that the fish loss was due to a decline in the dissolved oxygen since all of them perished at night. The large

population of game fish in the lake was not affected. In order to test the toxicity of the algae, a two cubic centimeter suspension of *Anabaena flos-aquae* from the lake was administered to a laboratory rabbit by pipette at 3:30 p. m. At 4:00 p. m. the animal showed signs of distress, with minor abdominal convulsions and some loss of control of the hind legs. At 4:45 p. m. characteristic flaccid paralysis of the motor nerves had developed, and at 5:10 p.m. the animal was dead. In view of these circumstances, the lake was closed to all swimming and the public notified that the lake was in a dangerous condition.

Since 1948, several serious losses of migratory waterfowl have occurred that has caused much local concern. Due to this threat to public health, livestock and waterfowl, the Storm Lake City Health Physician, State Conservation Officer and Lake Patrolman have cooperated in a constant check on the algal blooms. Collections are made regularly and examined by the doctor for the presence of *Anabaena.* As soon as it appears and proves toxic to laboratory animals, the beaches are closed and the public notified. Usally the bloom disappears prior to fall migration of waterfowl; however, this is not always the case.

In the fall of 1952, the most serious development of poisonous *Anabaena flos-aquae occurred* that has ever been witnessed in the Iowa lakes. Prolonged "Indian Summer" conditions prevailed, and huge quantities of *Anabaena,* accompanied by lesser amounts of *Aphanizomenon* and *Microcystis* developed. All of the lee shores and bays were literally filled with algae to a porridge-like consistency. Early in October, 1952, an estimated 2,000 Franklin's Gulls died on Storm Lake, and upon microscopic examination of lake water on October 13, it was found that the profuse bloom was composed almost entirely of the *Anabaena flos-aquae.* The plants were all green and fresh, with no evidence of decomposition. Large quantities of spores had formed in each cell colony. It is possible that the spore forming period may be the most toxic stage of its life-history; however, considerable research would be necessary to determine this rather academic factor. Again on October 29, a heavy loss of Franklin's Gulls, together with a few Herring Gulls, ducks and coots occurred. At this time it was estimated that about 5,000 Franklin's Gulls were dead or dying on the lake. A total of 21 ducks (14 mallards, 4 ruddies and 3 greenwinged teal) were picked up from the open waters of the lake. Seven of the ducks were still alive and several gulls were obtained that were partially paralyzed. The live ducks upon transfer to a stock watering tank soon recov-

ered and were released after wind action broke up the lake's deadly surface accumulation of algae. All of the losses to date have been during very calm weather, or when slight shifting breezes dispersed the algae in "lanes" of high concentrations over the lake surface from lee accumulations. Again on November 16, the lake was very calm and another loss occurred principally in mallard ducks. A total of 60, weak and partially paralyzed ducks were picked up from the lake by boat and transferred to a large pen on shore. Game Biologists flushed their digestive tracts with a solution of potassium permanganate and epson salts. These ducks were transferred to a game nursery at Lake View, Iowa, where all but three of the ducks completely recovered, were released and continued their migration.

In order to obtain data concerning definite etiological factors involved in these losses, a number of dead and dying gulls, ducks and coots were collected on October 24, and sent to the Veterinary Clinic at Iowa State College for examination and study. Also, a large quantity of fresh *Anabaena* was included in collection jars for experimental work. A report from Dr. Lloyd D. Jones, D. V. M. of the Iowa Veterinary Diagnostic Laboratory concerning their studies states ". . . Examination of these fowl revealed them to be suffering from a poisoning. Amounts of this material (Algae) were force-fed and voluntarily fed to chickens, guinea pigs, rabbits and mice with the results of death in all cases. Bacterial filtrates inoculated into these animals also resulted in sudden death. The neutralization tests of bacterial filtrates using botulinus antitoxin A, B and C all produced negative neutralization results." This is an important factor since it definitely rules out botulism as a possible cause of the deaths. The report continues ". . . it is my opinion that the death of these animals was due to a toxic substance incidental to the high concentration of algae present in the water. Bacteriological studies conducted on the vital organs of a representative sample of the birds yielded negative results. Another test was made on December 8, 1952, of the algae collected on October 24, and it proved to be just as toxic as when first received."

The total loss of animals that have been killed by poisonous algae at Storm Lake this fall (1952) by the *Anabaena* have been recorded by Frank Starr, State Conservation Officer, as follows: Franklin's Gulls, 5,000 to 7,000; ducks, 560; coots, 400; pheasants, 200; fox squirrels, 50; muskrats, 18; dogs, 15; cats, 4; hogs, 2; hawks, 2; skunk, 1 and mink 1. Also, numerous song birds were observed dead along the beaches. The above list is doubtless not exact, but is the record of those animals burried by the officer.

Dickinson County Lakes

Other lakes in Iowa have on comparatively rare occasions developed similar poisonous blooms of blue-green algae. In the fall of 1944 and again in 1945, heavy losses of livestock occurred including a known 37 hogs, 4 sheep, 2 cattle, 3 horses and several dogs, cats, squirrels, chickens, turkeys and songbirds. These losses were all on East Okoboji, Lower Gar and Center Lakes. The bloom at that time contained primarily *Anabaena flos-aquae*.

The Veterinary Research Institute at Iowa State College, the State Board of Health and the State Conservation Commission cooperated in an investigation of these losses. Some reports of these studies may be of interest. From Dr. H. F. Beardmore, Assistant Professor of Veterinary Pathology, ". . . bacterial free filtrate from this algae material which has upon injection into guinea pigs produced that typical symptoms which have been described in the literature by previous workers. Thus we feel without any doubt that these losses occurring on the lake were due to this plankton toxicosis . . . ." Also, from Dr. H. E. Biester, Assistant Director of Veterinary Research Institute, a letter of November 13, 1945, ". . . The algae samples sent by you arrived in excellent condition. Both of these samples contained toxic properties, killing laboratory animals upon injection of the crude material. The three samples from Center Lake (*Anabaena* entirely) proved toxic in crude as well as refined material." A report from Dr. W. G. Port, of the State Department of Agriculture, described the studies of Dr. Beardmore in some detail as follows: ". . . the material (algae) was processed into bacterial free filtrate—when this process was completed, approximately 10 to 15 cubic centimeters were injected intraperitoneally into two guinea pigs. Both of these pigs were dead in 12 minutes . . . . Four tenth of one cubic centimeter of the same material was injected into a mouse which lived only about four minutes. It is interesting to note that from the material collected last year, two cubic centimeters were retained in the laboratory. Approximately one cubic centimeter was injected into a mouse which did not succumb. This of course indicated that no toxin was contained therein after a period of one year."

Nature of the Toxin

Almost all of the toxins produced by poisonous plants are complex organic substances that are difficult to isolate. The toxin or toxins produced by certain species of blue-green algae have likewise been almost impossible to determine. All of the blue-greens contain large quantities of plant protein in their cytoplasm, and the possi-

bilities of various highly poisonous substances being formed while fresh or in putrefaction is of course very great. Grinnell College chemists isolated hydroxylamine and methylamine from decomposing *Aphanizomenon* in the previously mentioned report by Prescott (1931). The suggestion that iso-cyanides are produced by healthy blue-green algae is of course tenable, but isolation has not been verified and specific tests for cyanide have been negative. Olson (1952) states " . . . the isolation and separation of toxic elements from the algae, the nature of the substance or substances which may be concerned has not been accurately determined. It would appear that more than one substance is involved and that the symptoms produced are a result of the combined action of these elements."

Apparently the toxic agent or agents are developed only during certain unpredictable periods in the life history of the algae, and that they are highly unstable substances. Center Lake has had blooms of *Anabaena flos-aquae* in varying densities for years, but no reports of livestock losses other than mentioned here have ever occurred. It is altogether possible that these algae are toxic in varying degrees at all times, but that high concentrations are necessary such as exist during heavy blooms to produce losses to birds and mammals. Thus possibly a lethal dosage may be a function of the volume of algae ingested rather than a vastly increased potency during a particular phase in their life history.

Many thousands of waterfowl and shore birds die annually from variously assigned maladies including botulism, alkali poisoning and lead poisoning. It is now suspected that many of these heavy losses may be attributable at least in part to algal poisoning. McLeod and Bondar (1952) commented on the similarity of symptoms of these maladies in Manitoba lakes where losses have extended into "tens of thousands". The algae experiments conducted by them involved primarily *Aphanizomenon,* which had caused substantial losses in livestock at Lake Dauphin. They noted that the potency of their samples was considerably below those reported by Olson (1951), and it was certainly lower than those tested in Iowa.

Inasmuch as the toxin developed by these blue-green algae is occasionally extremely potent the potential danger to man should not be minimized. Many cottage owners along the shores of Storm Lake and other Iowa Lakes have sand-point wells that might carry the toxin in lethal quantities to these people. Also, thirsty children could conceivably drink water from the lake with tragic results. Olson (1951) cited several instances which indicated toxins from blue-green algae had likely been responsible for several serious

intestinal disturbances in cities with modern water treatment plants.

It might be inferred that in Iowa, the only poisonous species of blue-green algae is *Anabaena flos-aquae*. Certainly our experiments point toward this; however, other nearby regions have evidence that other species of this genus and other genera may be equally toxic. McLeod and Bondar (1952) proved *Aphanizomenon flos-aquae* as toxic in Canada. Clinical data of Olson (1951) involves definitely two other species, *Microcystis aeruginosa* and *Anabaena Lemmermanni,* although many others were mentioned that were associated with losses of livestock. According to Ingram and Prescott (1952) the following genera appear to have toxic species: *Microcystis, Anabaena, Aphanizomenon, Nodularia, Gleotrichia* and *Coelosphaerium. Aphanizomenon* develops extremely heavy blooms in the Iowa lakes, and West Okoboji Lake often has heavy scums of *Gleotrichia;* however, they have never caused losses of domestic livestock or waterfowl to my knowledge.

Conclusion

In view of the increasing demand for recreational areas in Iowa, and with our limited number of lakes, it is desirable that all bodies of water be as suitable for total recreation as possible. Due to the many unwholesome manifestations and toxic properties of some species of algae, the use of algacides as a palliative will probably become necessary in extreme instances. The development of natural controls is highly desirable, and it is hoped that further research will provide a practical solution. The elimination of all municipal pollution, and other sources of fertility may, in the long run, aid in natural control of algae; but, the Iowa lakes are drainage basins of some of the world's richest lands. Consequently we can expect these lakes to be equally rich in the elements from the soils. Therefore, local pollution is but one factor in the stimulation of bloom-forming plants. The introduction of the gizzard shad is not recommended since the problems of fish management becomes more acute than the control of algae.

The problem of providing clean, safe waters for recreation, public health, migratory waterfowl, domestic and game animals is serious throughout the north-central lake region of North America. A considerable amount of research is being conducted by individual States and Canadian Provinces toward the determination of causes and control of algal blooms. An expansion and integration of these studies is indicated as a very real need.

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