Influence of disease, toxins, and contaminants on declining muskrat populations

Abstract: The muskrat (*Ondatra* zibethicus) is a medium-sized semiaquatic rodent native to North America. For several decades, trappers in the Midwest and the northeastern United States have been aware that populations of muskrats have been declining and their distribution reduced. Similarly, wildlife managers have recorded declines in muskrat harvests. The overall declines in regional population trends for muskrats are alarming. As such, the Ohio Division of Wildlife, working in cooperation with the Wilds, launched an ambitious project to methodically examine potential factors that could be contributing to the muskrat decline. Our first step was to examine their health, and determine exposure to toxins and other chemicals. Accordingly, objectives of this study were to collect muskrat carcasses from across Ohio to determine health in terms of (1) presence of disease, (2) accumulation of toxins, and (3) detrimental effects of contaminants. Sex and age structure, as well as reproductive output were also determined for the sample population. Trappers across Ohio donated legally trapped muskrats for this study. A total of 592 muskrats from the 2013-14 and 2014-15 trapping seasons from across the state were necropsied. Based on molar indices, approximately 11% of the samples were adults. All adult females had reproduced, having 1–3 litters/year with an average placental scar count of 15.0 ± 6.1 (range 3 – 32). Sex ratio was 1.1 males for every 1.0 female, which is close to an even ratio. These demographic variables are typical for muskrats at Ohio's latitude. Few gross abnormalities of carcasses were noted during necropsy. White lesions noted on the livers of six muskrats were diagnosed as strobilocercus, which are bladder-like cystic structures formed by taenioid tapeworm larva. Their low level of occurrence suggested they were not a potential threat to population health.

Pesticides and personal care products appeared to play a minor role in muskrat toxicology; however, metals were much more significant with 19 of the 23 tested elements occurring at above threshold values. Forty muskrats exhibited exposure above threshold limits for 1 to 18 metals. Less than 25% of the individuals ($n \leq 9$) were exposed to aluminum, arsenic, boron, chromium, cobalt, copper, cadmium, lead, nickel, selenium, silver, vanadium, and zinc. Overall, three to nine individuals exhibited exposure to these metals, often at the severe level. Three muskrats from disparate areas, Ashland, Fayette, and Guernsey counties, exhibited exposure to 18, 17, and 18, of the 23 metals for which we tested, respectively. The exposure to six metals was more widespread and consequently has the potential to cause detrimental effects on a large scale. These were antimony ($n = 19$ muskrats), calcium ($n = 19$), iron ($n = 21$), mercury ($n = 21$), molybdenum ($n = 19$), and strontium ($n = 22$). Muskrats in areas across Ohio suffer from moderate to severe levels of metal contamination. Such contamination can have negative effects on health, survival, and reproduction. However, the pathogenic effects of contaminants cannot be known without additional testing. Histological tests on major organ tissues are needed to determine if and to what extent contamination with metals is impacting muskrat populations in Ohio.

INTRODUCTION

The muskrat (*Ondatra zibethicus*), the only species in the genus *Ondatra* and tribe Ondatrini, is a medium-sized semiaquatic rodent native to North America, and has been introduced into parts of Europe, Asia, and South America (Boutin and Birkenholz 1987, Errington 1963). Muskrats occupy almost every type of freshwater aquatic habitat and are typically the dominant herbivore in these systems (Erb and Perry 2003). The muskrat has played and continues to play a vital role in fur trapping, and is one of the most widely distributed and important furbearers in North America (Boutin and Birkenholz 1987, Errington 1963). In Ohio, the number of muskrats and raccoons (*Procyon lotor*) taken for fur have typically outnumbered that of all other species since the earliest records in 1933.

In addition to their importance to fur harvest, muskrats are critical to the structure and function of aquatic ecosystems (Connors et al. 2000, Weller 1981, Weller and Fredrickson 1973). Being an r-selected species, they quickly overpopulate a marsh or other aquatic system. In marshes, they have the ability to open the vegetation to optimize productivity or to over utilize the habitat, thereby degrading its suitability for themselves as well as other species (Danell 1979, Smirnov and Tretyakov 1998). Thus, the muskrat's effects on vegetative structure can affect invertebrate (de Szalay and Cassidy 2001, Nelson and Kadlec 1984, Nummi et al. 2006) and bird communities (Kaminski and Prince 1981, Bishop et al. 1979).

Muskrats can also serve as indicators of ecosystem health by responding to various toxins and chemicals that commonly degrade aquatic habitats (Erickson and Lindzey 1983, Halbrook et al. 1993, Stevens et al. 1997). They may also serve as early indicators of toxic compounds and elements. Rudneva et al. (2003) found that muskrats accumulated several chemical elements that were not detected in fish at the same location. Heavy metal increases in tissue of muskrat can indicate increased industrial waste contamination, and consequently muskrats have the potential to serve as useful bioindicators of metal pollution in semi-aquatic environments (Parker 2004). As such, conserving viable muskrat populations is critical for proper ecosystem structure and function, as well as their role as an early indicators of toxic stressors.

For several decades, trappers in the Midwest and the northeastern United States have been aware that populations of muskrats have been declining and their distribution reduced. Numerous sources suggest that muskrat densities have declined at sites once inhabited by thriving populations and that once lost from an area, muskrats are not likely to reestablish themselves. Similarly, wildlife managers have recorded declines in muskrat harvests throughout the Midwest and northeastern United States and eastern Canada (Northeast Fur Resources Technical Committee 2005). The overall declines in regional population trends for muskrats are alarming.

Thus, the decline in muskrats is real and widespread, possibly affecting the entire eastern U.S. It is likely that the muskrat faces a number of negative impacts, which taken together have caused the decline. Roberts and Crimmins (2010) noted that recent harvest rates showed little correlation with current or time-lagged pelt prices, whereas strong correlations between pelt price and harvest existed for historic data (1948–1968). Similarly, pelt price and muskrats harvested and sold in Ohio were highly correlated until the mid-1990s, after which muskrat harvest fell, remained low despite rising pelt prices, and the correlation no longer existed (Fig. 1). As such, the Ohio Division of Wildlife, working in cooperation with the Wilds launched an ambitious project to methodically examine potential factors that could be contributing to the muskrat decline. Our first step was to examine their health, and determine exposure to toxins and other chemicals. Determination of the demographics of Ohio's muskrats, including sex ratio and age structure, as well as reproductive output was also a goal of this initial study.

Accordingly, objectives of this study were to collect muskrat carcasses from across Ohio to determine health in terms of (1) presence of disease, (2) accumulation of toxins, and (3) detrimental effects of contaminants. Sex and age structure, as well as reproductive output were also determined for the sample population.

METHODS

Trappers across Ohio were asked to donate legally trapped muskrats for this study. Most animals received were skinned carcasses. Carcasses were frozen at -20°C until necropsy. Necropsies were performed on all carcasses. Standard measurements and body weights were recorded to determine condition indices. Internal abnormalities were noted and photographed. All internal organs were preserved for further testing.

Reproductive status was noted and placental scars were counted when present. The first molar was removed from all carcasses and the molar:root ratio (Pankakoski 1980) was used to determine age (adult or juvenile) for all individuals from which teeth were available . Sex and age ratios (juveniles to adults) were determined. Kidney, fat, and liver samples were taken from all carcasses for toxicological analyses. Because toxins accumulate over time in a body, we chose to test only adults. Samples from 41 adult muskrats were submitted for toxicological tests to ALS Laboratory (Kelso, Washington, USA). Tissues were tested for the presence and levels of 23 metals, 116 organophosphate and organochloride pesticides, and 12 potentially toxic human health and personal care products.

RESULTS

A total of 592 legally taken muskrats from the 2013-14 and 2014-15 trapping seasons were donated by trappers from across the state. Samples came from 43 of Ohio's 88 counties. The sampled counties were well distributed and included 9 counties in central, 6 counties in northwestern, 14 counties in northeastern, 7 counties in southeastern, and 7 counties in southwestern Ohio (regions based on ODOW Districts). Most of Ohio's wetlands are in the northeastern portion of the state, and consequently more counties were represented in this region.

Based on molar indices, approximately 11% of the samples were adults (Fig. 2). Placental scar counts were completed for all females to document reproductive output. All adult females had reproduced, having 1–3 litters/year with an average placental scar count of 15.0 ± 6.1 (range 3 – 32). This reproductive rate is typical for muskrats at Ohio's latitude. Sex ratio was 1.1 males for every 1.0 female, which is close to an even ratio.

Few gross abnormalities of carcasses were noted during necropsy. The most common was the occurrence of multiple large, white lesions on the livers of six muskrats. The lesions were diagnosed as strobilocercus, which are bladder-like cystic structures formed by taenioid tapeworm larva. Their low level of occurrence suggested they were not a potential threat to population health. All major organs were frozen at -20°C for possible further evaluation. A subsample of carcasses (n = 100) were sent to Ohio Wesleyan University for parasite screening. These analyses are ongoing.

Because contaminants are more likely to be detected in adults, given the additional time for accumulation in tissues of these animals, only adult tissues were used in toxicological analyses. Therefore, 41 adult samples were tested. All toxins were categorized as being within or above the threshold level for potential adverse effects. Threshold values were based on published levels for muskrats or similar species, and/or US or state limits and regulations. Levels above the threshold were further characterized as mildly, moderately, or severely elevated based on the concentration of the toxin. It is noteworthy that these latter categories were subjective. Furthermore, mildly elevated does not denote a mild effect of the toxin; the term mild describes the level of increase *above* the threshold level for deleterious effects. Of the 41 samples, 40 were found to have above threshold levels for at least one element or compound. The 40 muskrats carried burdens from 1 to 18 toxins. Few positive results for pesticides were found. One muskrat exhibited a mild elevation for mirex (Marion County), and another showed a moderately elevated level for isodrin (Wayne County). Two muskrats were exposed to deildrin, one moderately (Allen County) and one severely (Delaware County). All of these compounds are related to organochloride insecticides that were banned because of their impact on the environment during the 1970s. No currently used pesticides were detected. Of the personal care products, caffeine was detected at moderate levels in two muskrats (Summit and Trumbull counties).

Although pesticides and personal care products appear to play a minor role in muskrat toxicology, metals were much more significant with 19 of the 23 tested elements occurring at above threshold values. All 40 muskrats exhibited exposure above threshold limits for 1 to 18 metals. Less than 25% of the individuals ($n \leq 9$) were exposed to aluminum, arsenic, boron, chromium, cobalt, copper, cadmium, lead, nickel, selenium, silver, vanadium, and zinc (Table 1). Overall, three to nine individuals exhibited exposure to these metals, often at the severe level. Three muskrats from disparate areas, Ashland, Fayette, and Guernsey counties, exhibited exposure to 18, 17, and 18, of the 23 metals for which we tested, respectively.

The exposure to six metals was more widespread and consequently has the potential to cause detrimental effects on a large scale throughout the state. These were antimony ($n = 19$ muskrats; Fig. 3), calcium ($n = 19$; Fig. 4), iron ($n = 21$; Fig. 5), mercury ($n = 21$; Fig. 6), molybdenum ($n = 19$; Fig. 7), and strontium ($n = 22$; Fig. 8).

DISCUSSION

Necropsies revealed few gross abnormalities. However, the evaluation potential of gross necropsies for diseases is quite limited. Histological analyses of major organs would be beneficial in this respect, but tissues for histology must be fresh and not subjected to below freezing temperatures. Two major diseases of muskrats are tularemia and Tyzzer's disease. Liver spots characteristic of tularemia were not observed. Tyzzer's disease must be diagnosed by the identification of the causative organism, which again is often performed by histology. Nonetheless, the nature of the decline in muskrats, being widespread and long term, is not indicative of the cyclic nature of most disease processes.

Sex ratio was slightly skewed toward males. Similarly, Beer and Truax (1950) examined data from over 89,000 muskrats from various localities and found an overall sex ratio of 55%

males to 45% females. Doude van Troostwijk (1976) also reviewed muskrat sex ratios and found that sex ratios in all age classes favored males. Our mean value of 15.7 placental scars for adult females was similar to estimated reproductive output in areas at similar latitudes. Errington (1963) estimated 12 to 16 young born annually per female in Iowa. Erb (1993) found an average of 15.5 young per female annually in Missouri. This is in agreement with the age structure of our sample population, which was composed of 89% juveniles. The proportion of juveniles to adults is typically very high in muskrats. However, there have been numerous reports from trappers regarding the lack of reproduction in muskrats. In support of this, no kits occurred in our sample population. Wilson (1956) stated the 6.6% of harvest muskrats were kits in North Carolina. Similarly, Lay (1945) reported 8% kits in a moderately trapped marsh in Texas. The broad range in the number of placental scars per adult female (3 – 32) and the absence of kits in the harvested samples does not allow us to rule out declines in reproductive output as a contributing factor to the observed decline in muskrat populations. Furthermore, placental counts are often higher than the number of kits actually born, and certainly higher than those that survive.

Of the metals for which we tested, 19 of 23 occurred at above threshold values in our sampled muskrats. Only one of the 41 sampled muskrats did not suffer from a significant burden from metals. Eleven of the 19 metals occurred in less than 25% of our sampled muskrats. Although the levels were in some cases severe and the metal burden likely resulted in pathologic effects, we are limiting the remainder of our discussion to the six metals that occurred in more than 25% of our samples and consequently have a greater likelihood to be contributing to the observed state wide population decline.

Antimony

Antimony enters the environment during mining and processing of its ores and in the production of antimony metal, alloys, antimony oxide, and combinations of antimony with other substances. Little or no antimony is mined in the United States. Antimony ore and impure metals are brought into this country from other countries for processing. Small amounts of antimony are also released into the environment by incinerators and coal-burning power plants. The antimony that comes out of the smoke stacks of these plants is attached to very small particles that settle to the ground or are washed out of the air by rain. Oral animal studies have reported effects on the blood, liver, central nervous system, and gastrointestinal effects. Animal studies have also reported a decrease in the number of offspring born to rats exposed to antimony prior to conception and throughout gestation. Reproductive effects, including metaplasia in the uterus and disturbances in the ovum-maturing process, were reported in a rat study, following inhalation exposure.

Mercury

Hair samples were taken from the inguinal and lumbar regions of 58 muskrats from four sites in the Oak Ridge Reservation, Tennessee (Stevens et al., 1997). Mercury was detected in 75% of all hair samples, 90% of adult samples, and 45% of juvenile samples. Mean concentrations in adults were 0.24 µg/g dry weight in contaminated sites and 0.13 µg/g at reference sites. From 1972 to 1975, 14 muskrats trapped from the Wisconsin River were analyzed for mercury in the fur, liver, kidney, muscle, and brain (Sheffy and St. Amant, 1982). Mercury in all tissues except fur occurred at concentrations below the 0.02 µg/g detection limit. In 1974, muskrat samples were collected from four locations in Pennsylvania for metal analysis (Everett and Anthony, 1976). Our threshold value was 0.0192 µg/g, with an above threshold mean of 0.098 µg/g (range 0.0194 to 0.5077).

Coal-fired power plants are the single largest source of mercury contamination in the U.S., responsible for approximately 50% of human-caused mercury emissions. Other sources include waste incinerators that burn mercury-containing products and chlorine manufacturers. Mercury is a highly potent neurotoxin that impacts the function and development of the central nervous system in both people and wildlife. Significant effects on reproduction are also attributed to mercury, and methylmercury poses a particular risk to the developing fetus because it readily crosses the placental barrier and can damage the developing nervous system.

Calcium

Mercury and calcium can be highly interrelated. Mercury, acts on the bone cells and influences calcium homeostasis and induces hypercalcemia, or the excess of calcium in the blood and tissues.

Molybdenum

Molybdenum toxicity has been encountered in regions of the world containing peat, muck, or shale soil types that are naturally contaminated with molybdenum. Industrial contamination associated with mining or metal production or areas using molybdenum-contaminated fertilizers result in enhanced uptake of molybdenum by plants. Animal experiments have shown that too much molybdenum causes fetal deformities.

Strontium

Strontium, like mercury, is highly tied to calcium, but for another reason. Strontium and calcium are very similar. When present in high amounts, enough strontium may be taken into bone (instead of calcium) to weaken growing bones. Strontium has more severe effects on bone growth in young animals than in adults. Studies have demonstrated an association between the accumulation of strontium in bone and the presence of osteomalacia. The uptake of strontium has been shown to be dose-dependent, with distribution mainly in newly formed compact and cancellous bone. Animal studies demonstrated that high doses of strontium induced alterations of mineralization and, in a rat model of chronic renal failure, high strontium doses induced mineralization defects, with a corresponding 160-fold accumulation of strontium in bone (Cohen 2002). Studies indicated that the accumulation of metals in bone might be synergistic. Aluminum in bone content was higher when both aluminum and strontium were administered compared with strontium alone.

CONCLUSIONS

Muskrats in areas across Ohio suffer from moderate to severe levels of metal contamination. Such contamination can have negative effects on health, survival, and reproduction. However, the pathogenic effects of contaminants cannot be known without additional testing. Histological tests on major organ tissues are needed to determine if and to what extent contamination with metals is impacting muskrat populations in Ohio. Correlation with tests of water and/or plant tissue may offer information on the bioaccumulation cascade within Ohio ecosystems and could help to assess contamination of muskrats in waterways in all counties. This study represents an initial effort to determine the factors affecting muskrat population declines, and provides a groundwork upon which to base future studies. Beyond metals, herbicides and polyaromatic hydrocarbon pesticide levels should be examined. Multiple exposure to metals and other toxins can have synergistic negative effects. Contamination will be assessed in terms of habitat (e.g., pond, ditch, river, etc.), as well as sounding land use (e.g., agricultural, industrial, residential, etc.). In the end, we hope to develop a comprehensive picture of effects of contaminant burden on muskrats in Ohio.

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Table 1. Level of contamination above threshold values (+ mild, ++ moderate, and +++ severe) for elements occurring in less than 25% of the sampled muskrats.

	Muskrat Number																				
Metal	119 Summ[1]	179 Fair	180 Fair	249 Athe	292 Morg	301 Alle	322 Colu	345 Ashl	558 Jeff	145 Summ	207 Athe	536 Jeff	574 Mari	278 Otta	308 Dark	434 Adam	547 Jeff	382 Guer	427 Ashl	604 Faye	Total Sites
Aluminum					+		+	+			++		+			+		+++	+++	+++	9
Arsenic																		++	++	++	3
Boron		+								+	+		++				+++	++	++	++	8
Chromium																		++	++	++	3
Cobalt																+		+++	+++	+++	4
Copper														+	+		+	++	++	++	6
Cadmium						+								+				++	++	++	5
Lead	+																	++	++	++	4
Nickel												+				++		+++	+++	+++	5
Selenium			+	+								+		+	+			++	++	++	8
Silver									+									+	+	+	4
Vanadium																		++	++	++	3
Zinc										+					+		+	+	+	+	6
Total Metals	1	1	1	1	1	1	1	1	1	2	2	2	2	3	3	3	3	13	13	13	

[1]County abbreviations: Adam = Adams, Ashl = Ashland, Athe = Athens, Colu = Columbiana, Dark = Darke, Fair = Fairfield, Faye = Fayette, Guer = Guernsey, Jeff = Jefferson, Mari = Marion, Morg = Morgan, Otta = Ottawa, Summ = Summit.

Table 2. Total number of contaminants detected at each level of severity above the threshold and overall level of contamination above threshold by county.

County	# of Mild	# of Moderate	# of Severe	Level of Contamination
Columbiana	2	1	0	Mild
Holmes	1	1	0	Mild
Lake	2	0	0	Mild
Licking	0	1	0	Mild
Logan	3	0	0	Mild
Preble	2	0	0	Mild
Adams	4	1	1	Moderate
Allen	5	2	0	Moderate
Athens	6	2	0	Moderate
Darke	8	1	0	Moderate
Delaware	3	0	1	Moderate
Fairfield	7	1	0	Moderate
Jefferson	15	2	1	Moderate
Lorain	6	2	2	Moderate
Marion	7	2	0	Moderate
Mercer	6	0	0	Moderate
Morgan	4	1	0	Moderate
Ottawa	7	2	0	Moderate
Summit	9	2	1	Moderate
Trumbull	3	3	0	Moderate
Wayne	3	0	1	Moderate
Ashland	5	11	6	Severe
Fayette	3	9	6	Severe
Guernsey	8	9	5	Severe

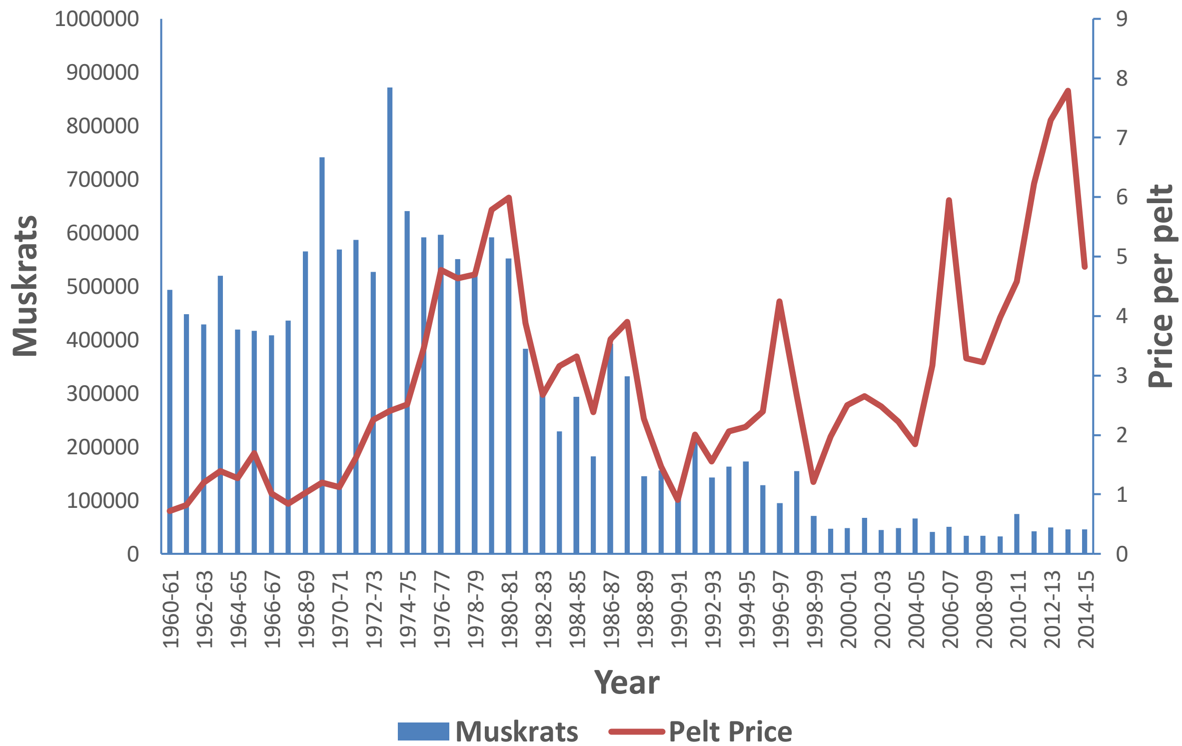

Figure 1. Number of muskrats harvested per trapping season relative to pelt price, 1960-61 through 2014-15.

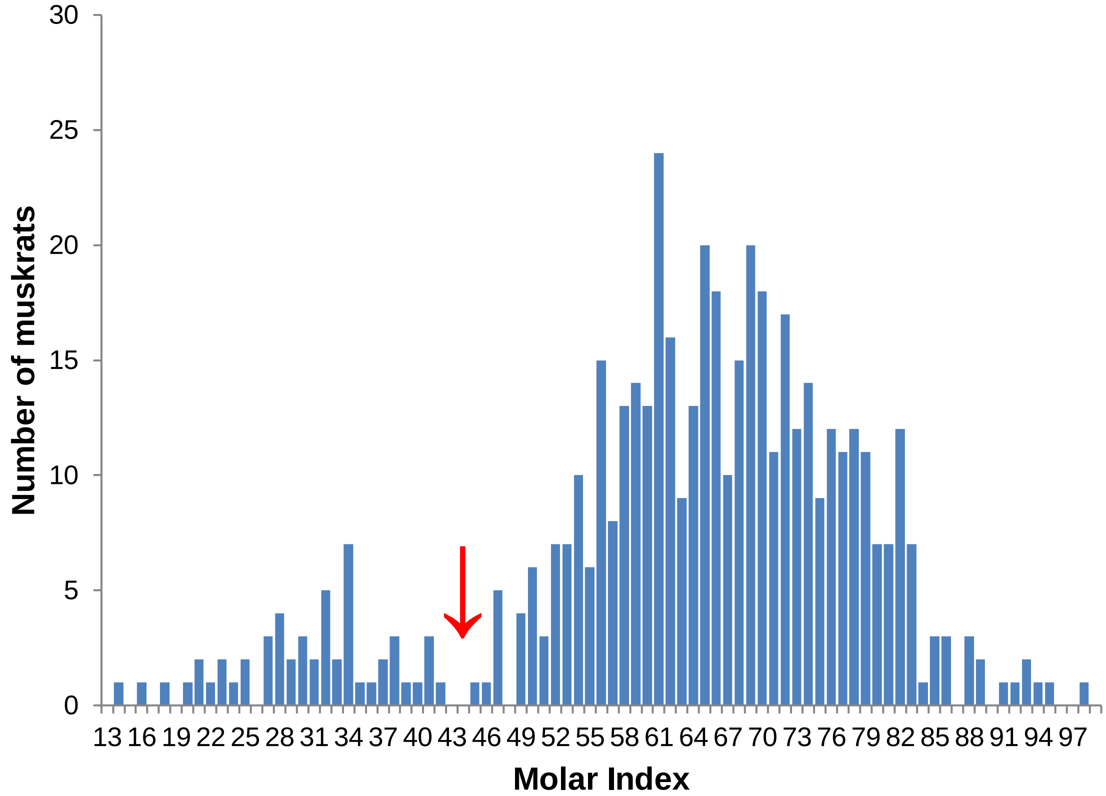

Figure 2. Molar index (molar:root ratio) of sampled muskrats. Lower values denote adults. The break in distributions (red arrow) indicates the critical value for discriminating adults from juveniles.

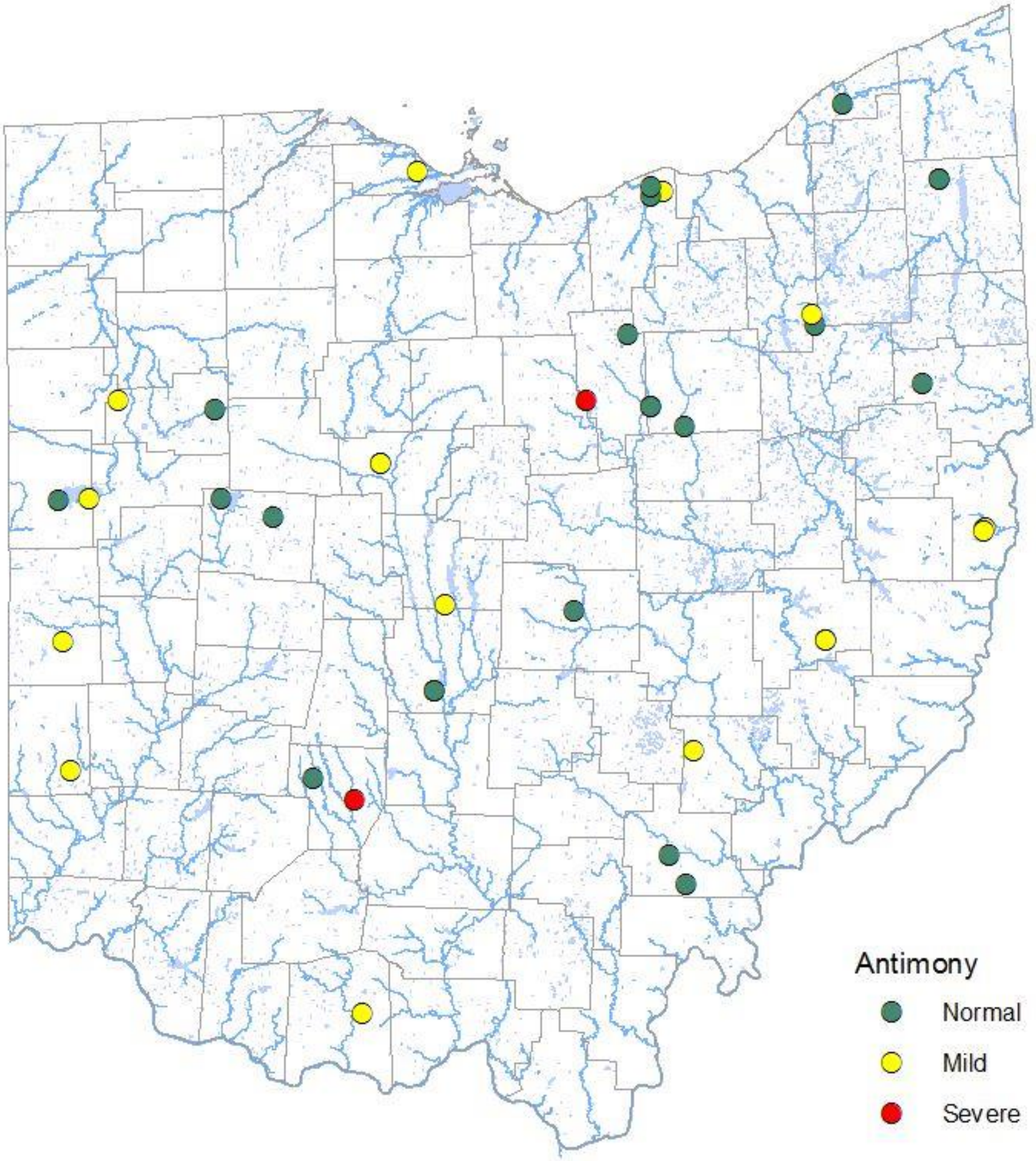

Figure 3. Levels of antimony above the threshold value by sampled muskrats for 41 muskrats sampled from areas across Ohio.

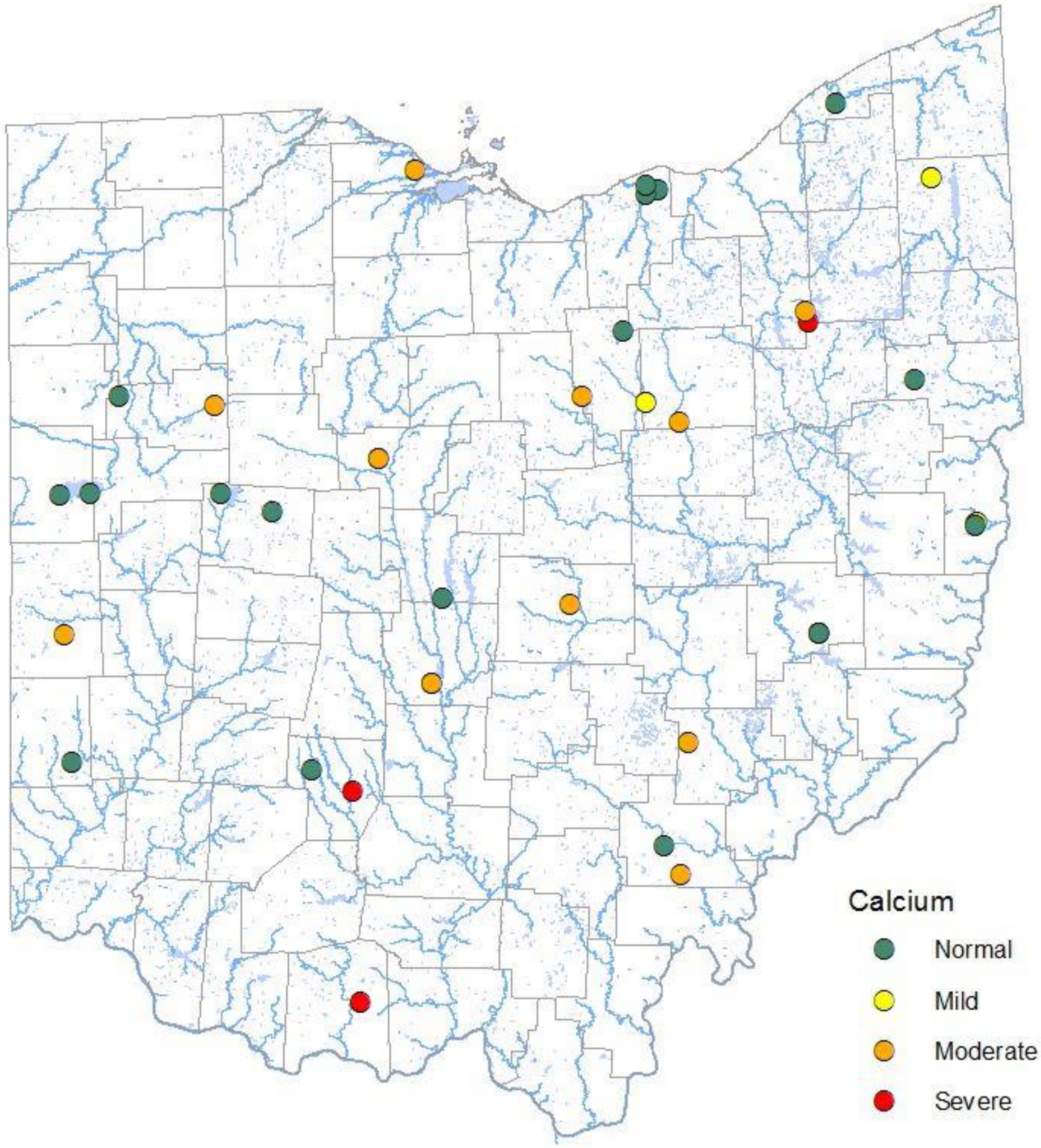

Figure 4. Levels of calcium above the threshold value by sampled muskrats for 41 muskrats sampled from areas across Ohio.

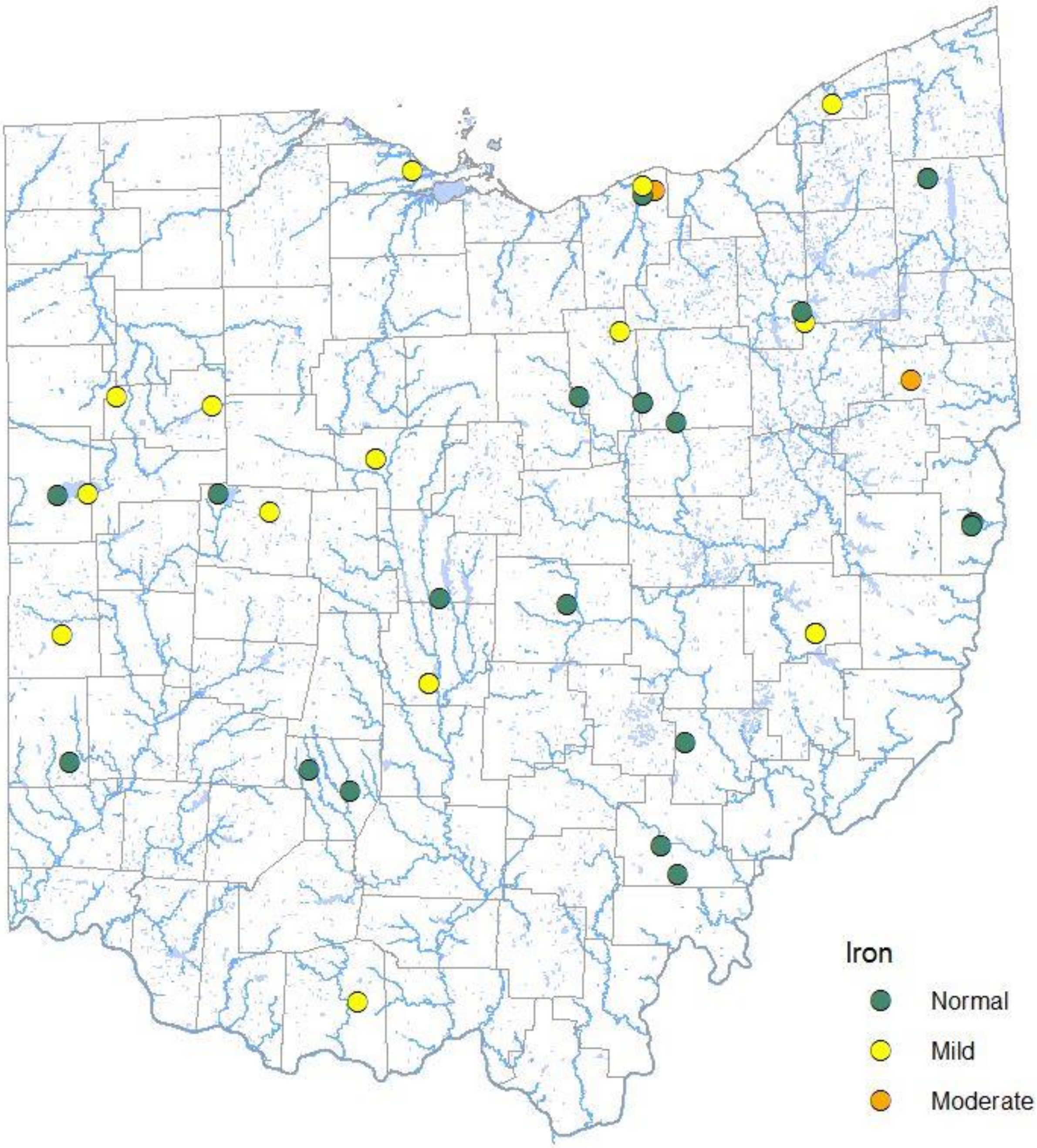

Figure 5. Levels of iron above the threshold value by sampled muskrats for 41 muskrats sampled from areas across Ohio.

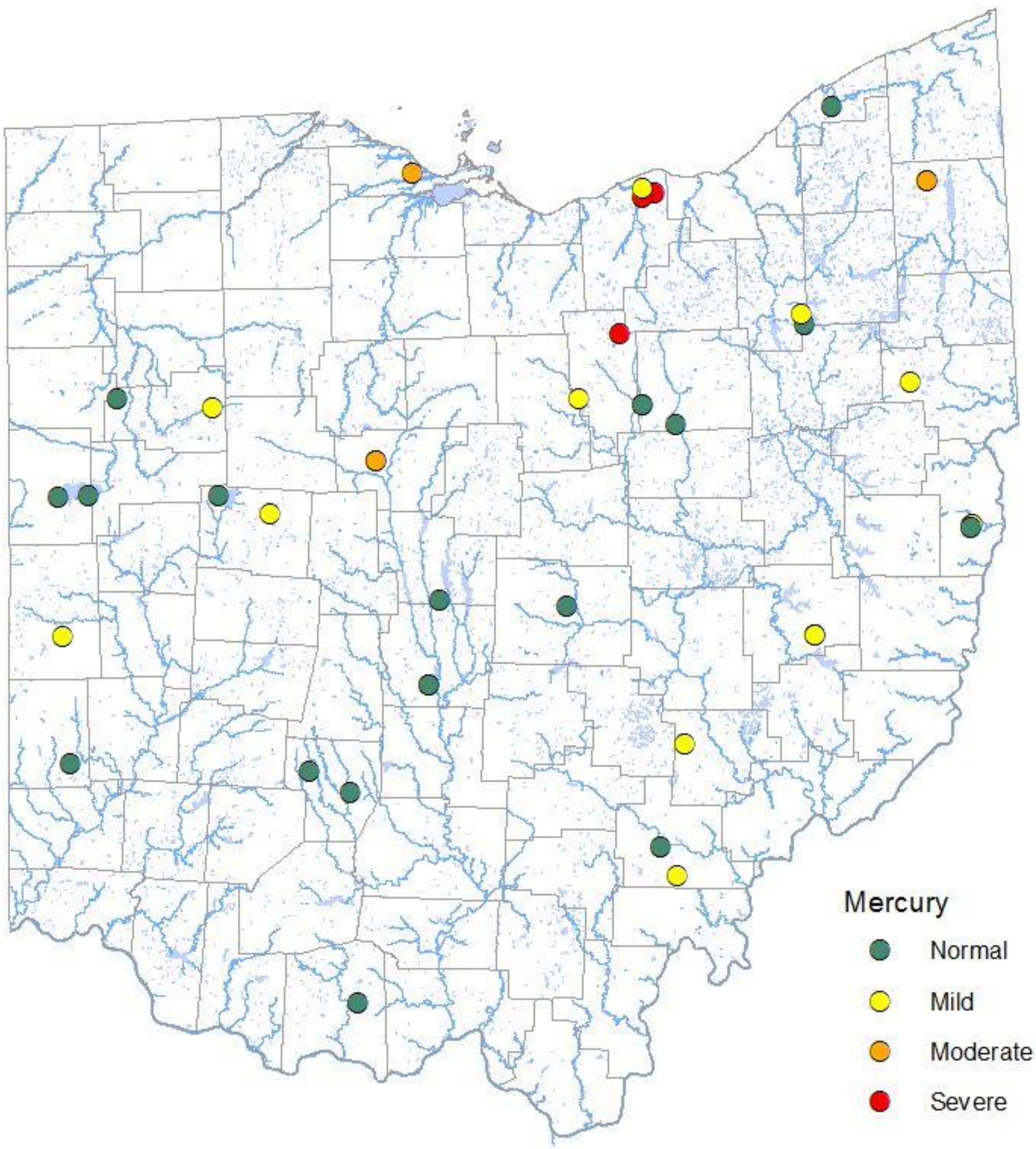

Figure 6. Levels of mercury above the threshold value by sampled muskrats for 41 muskrats sampled from areas across Ohio.

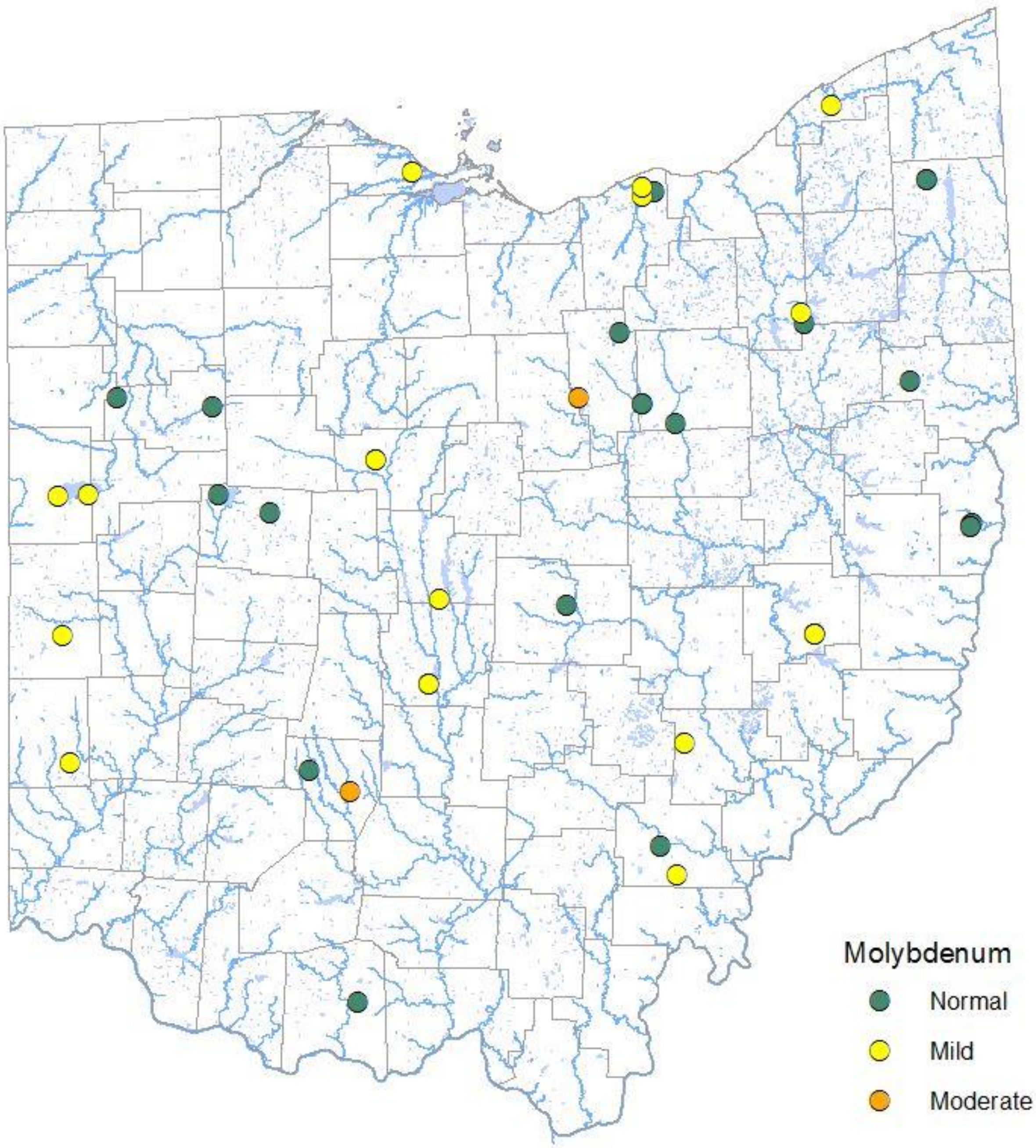

Figure 7. Levels of molybdenum above the threshold value by sampled muskrats for 41 muskrats sampled from areas across Ohio.

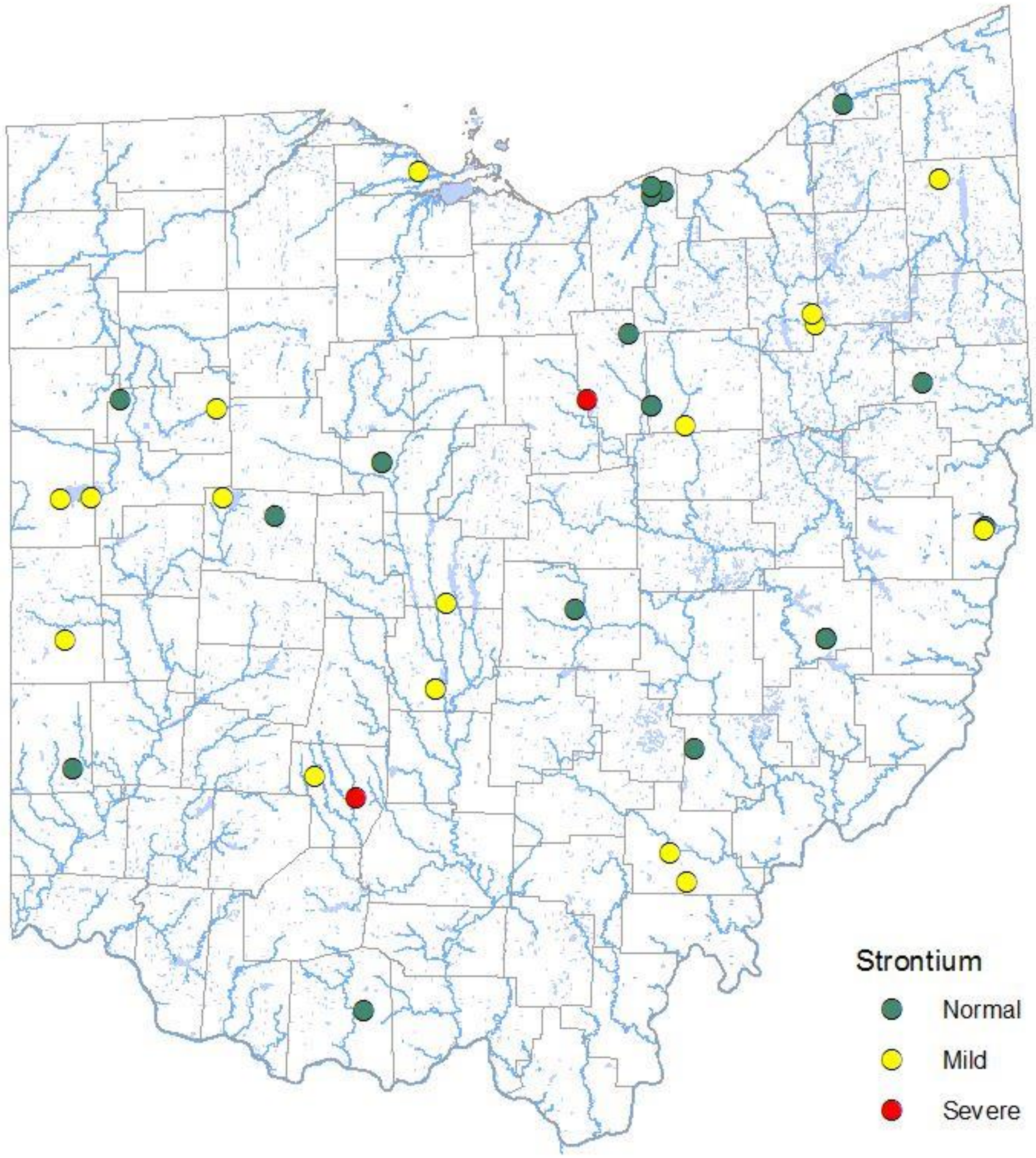

Figure 8. Levels of strontium above the threshold value by sampled muskrats for 41 muskrats sampled from areas across Ohio.