Spring 2012

Survey Of The Freshwater Gastropods Of Southeastern Kansas With Emphasis On The Distribution And Habitat Use Of The Delta Hydrobe (Probythinella Emarginata)

Bryan Sowards
Fort Hays State University, bjsowards@scatcat.fhsu.edu

SURVEY OF THE FRESHWATER GASTROPODS OF SOUTHEASTERN KANSAS WITH EMPHASIS ON THE DISTRIBUTION AND HABITAT USE OF THE DELTA HYDROBE (*PROBYTHINELLA EMARGINATA*)

being

A Thesis Presented to the Graduate Faculty

of the Fort Hays State University in

Partial Fulfillment of the Requirements for

the Degree of Master of Science

by

Bryan Sowards

B.S., Fort Hays State University

Date____________________ Approved___________________________________
Major Professor

Approved___________________________________
Chair, Graduate Council

This thesis for

the Master of Science degree

by

Bryan J. Sowards

has been approved by

____

Chair, Supervisory Committee

____

Supervisory Committee

____

Supervisory Committee

____

Supervisory Committee

____

Chair, Department of Biological Sciences

ABSTRACT

The status of many aquatic gastropods in North America is not well understood. Many are exposed to threats similar to those that affect bivalves and other aquatic macroinvertebrates. The delta hydrobe (*Probythinella emarginata*) is a gill-breathing (prosobranch) snail that occurs in the northeastern United States and eastern Canada. It is 1 of only 5 species of prosobranchs in Kansas and is highly sensitive to changes in water quality within watersheds. *Probythinella emarginata* is presumed to be a Pleistocene relic in the state; it was first collected alive in Kansas in 2001 within Cedar Creek, Chase County, Kansas.

I surveyed 13 sites on Cedar Creek, a second-order stream in the Flint Hills region of tallgrass prairie, in an effort to delineate the distribution and habitat preference of *P. emarginata*. In addition, 38 sites near Cedar Creek and in adjacent basins in southeastern Kansas were surveyed. Eleven species of freshwater gastropods were collected; *P. emarginata* was collected alive only in Cedar Creek, Chase County, and the Elk River, Montgomery County. *Probythinella emarginata* was the most abundant valve collected in Cedar Creek, but only 2 of 604 valves collected represented live individuals. This population, as judged by previous collections, has experienced a decline since 2001. Individuals from the Elk River population were collected among algae-covered bedrock in the lower portion of the basin. Densities of $3.7/m^2$ and $24.2/m^2$ were quantified from 2 sites in the Elk River but were restricted to downstream locations. *Probythinella emarginata* in the Elk River was positively associated with dissolved oxygen and negatively associated with edge-water habitat. The historical range retraction and habitat

restrictions of *P. emarginata* within both streams, and the decline in the Cedar Creek population, indicate this is a rare species vulnerable to extirpation from Kansas.

ACKNOWLEDGEMENTS

Many individuals deserve recognition for their support and assistance during this project. I thank my mentor and major advisor, Dr. William Stark, for the encouragement he provided throughout the project. His diverse knowledge of freshwater systems and hands-on approach to education facilitated my success at Fort Hays State University. I thank my graduate committee, including Dr. Greg Farley, Mark Eberle, and Ed Miller. I appreciate their constant support and guidance of all phases of the research from field advice and committee meetings to editing of this thesis. I thank Dr. Rob Channell for sharing his time and expertise to assist me with statistical analysis of the data. I also thank Dr. Elmer Finck, Chair of the Department of Biological Sciences, Dr. Jeff Briggs, Dean of the College of Health and Life Sciences, Sheila Pfeifer, the former Senior Administrative Assistant of the Department of Biological Sciences, and Kacie Vogt, Senior Administrative Assistant of the Department of Biological Sciences for their administrative assistance. The last three years would have been difficult without them.

Funding for the first year of the project was made possible through the Chickadee Checkoff Small Grants Program through the Kansas Department of Wildlife, Parks, and Tourism (KDWPT). I thank Ken Brunson, formerly with KDWPT, and Fort Hays State University for the logistics involved in funding the project.

Robert Angelo and Clint Goodrich with the Kansas Department of Health and Environment aided me in the daunting task of learning gastropod taxonomy. This was something I was not familiar with; I am grateful for their expertise. I, again, thank

Robert Angelo for information regarding the delta hydrobe and his constant support of my research.

I met many landowners who were willing to provide me with access to their properties. Field work would have been impossible without their support. I especially thank Pat Sauble, a landowner on Cedar Creek, Chase County, for regularly allowing me to camp and survey on his property. I thank Brian Obermeyer with The Nature Conservancy for providing me with information on the Cedar Creek watershed. I also thank Ryan Waters, Mark VanScoyoc, Jeff Conley, and Aaron Austin with KDWPT for providing information regarding the natural history of southeastern Kansas.

Field assistants were essential to completing the research in an efficient manner. I thank Ryan Pinkall for dedicating half his busy summer to my work. I also thank Weston Fleming, Jordan Hofmeier, Clinton Helms, Kyle Broadfoot, and Ryan Cox for providing me with field assistance.

I am grateful to the laboratory assistants for separating the gastropods from the sample material; this work was both time consuming and monotonous. I thank undergraduates Kyle Broadfoot, Jeff Carter, and Dylan Clabaugh for their efforts.

Finally, I thank my family for their love and support throughout this project. I especially thank my brothers, Dusty and Wesley Sowards, for inspiring me to continue with aquatic research. I cannot thank them enough.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PREFACE

This thesis follows the style of the Society for Freshwater Science.

INTRODUCTION

Mollusca is the second-most diverse animal phylum as judged by the number of described species world-wide (Lydeard et al. 2004). It is estimated that there are 31,000 extant species of non-marine mollusks (Lydeard et al. 2004). Many species are of conservation concern but are often overlooked, while more charismatic vertebrate species are studied and often featured in popular media (Lydeard et al. 2004, Lysne et al. 2008). However, mollusks have the highest number of documented extinctions of any major taxonomic group: 42% of all recorded animal extinctions (Lydeard et al. 2004). These extinctions are not directly related to the large number of molluscan species. Most mollusks are marine species and the conservation status of these forms seems to be relatively stable (Lydeard et al. 2004). Conversely, approximately 99% of mollusk extinctions have occurred among non-marine mollusks (Lydeard et al. 2004). Non-marine mollusks rely on freshwater for nearly all of their life processes and, therefore are increasingly constrained by river regulation, habitat loss, degraded water quality, and invasive species (Lysne et al. 2008).

Obligate aquatic bivalves (Bivalvia) and aquatic gastropods (Gastropoda) are of the greatest conservation concern because of alterations to their freshwater habitats. Bivalves have received most of the recent attention addressing conservation concerns, but snails and other gastropods are exposed to similar threats (Jenkinson and Todd 1998). Freshwater gastropods are an understudied, yet critically imperiled group of organisms; however, they are an important part of the trophic structure of aquatic systems (Newbold et al. 1983, Richardson et al. 1988, Brown 2001, Lysne et al. 2008).

Freshwater gastropods control the growth of algal communities, and grazed systems result in decreased algal biomass (Rosemond et al. 1993). Freshwater gastropods also provide an important food source for some species of fish and crayfish (Brown 1998).

There are 2 main groups of freshwater gastropods distinguished by their ecology, physiology, and evolutionary history: Pulmonata and Prosobranchia (Russell-Hunter 1978, Brown 1983, Brown et al. 1998). Pulmonates are derived from terrestrial gastropods; therefore, they have retained a simple lung used in gas exchange with the atmosphere. Pulmonate species of the families Planorbidae and Ancylidae are capable of gas exchange through dedicated respiratory pigments and gills, respectively (Brown et al. 1998). Pulmonates range from amphibious to obligate aquatic, depending on the family, and are most common in headwater streams (Brown et al. 1998).

Prosobranchs are derived from estuarine species (McMahon 1983) and have retained gills for gas exchange in water. Prosobranchs lack the adaptations to persist in areas with extended periods of hypoxia and extreme fluctuations of water temperature (Boycott 1936, Palmieri et al. 1980, Aldridge 1983, McMahon 1983, Brown et al. 1998). Also, most prosobranchs are dioecious and have male and female individuals of a species. Because pulmonates have a greater variety of gas exchange methods, they are less affected by low levels of dissolved oxygen (Boycott 1936, Palmieri et al. 1980, Aldrige 1983). Also, pulmonates have a greater tolerance to substantial variation in water temperature (McMahon 1983). All pulmonates are monoecious and have both sexes in each individual, which allows for greater reproductive potential (Brown 2001).

The morphology of pulmonates and prosobranchs differ considerably. Prosobranchs possess an operculum: a thin plate composed of a matrix of calcium and protein that is attached dorsally to the muscular foot. The operculum encloses the aperture, or opening, of the valve when the animal retracts into it and provides protection from predation, short periods of drought, and low levels of dissolved oxygen. The aperture in freshwater snails, when viewed ventrally with the apex oriented up is either sinistral, opening to the left, or dextral, opening to the right. Prosobranchs have dextral orientation and pulmonates exhibit sinistral or dextral orientations, depending on species. Prosobranchs have thicker valves than pulmonates, resulting in greater predation rates on the latter by fish and crayfish (Brown 1998).

Dispersal capacity of the 2 groups reflects their physiological, ecological, reproductive, and morphological characteristics. The lower drag coefficients of the valves of prosobranchs decrease downstream dispersal (Brown et al. 1998). The means of gas exchange limits prosobranch dispersal to areas of permanent water, with minimal fluctuation in temperature and high levels of dissolved oxygen. The reproductive limitations of dioecious prosobranchs results in relatively lower reproductive potential (Davis 1982, Brown 2001). The strategy of prosobranch reproduction decreases the effects of inbreeding depression (Brown 2001) but decreases the probability for long-distance dispersal. Brown et al. (1998) documented slower crawling rates and righting-response times in prosobranch versus pulmonate species. Consequently, these limitations of dispersal have contributed to smaller distributions and increased endemism of prosobranch gastropods.

There are approximately 842 species of freshwater gastropods throughout the United States and Canada (NatureServe 2007) and 48% of these are of conservation concern (Neves et al. 1997). The majority of these species, and the species listed as threatened or endangered under the Endangered Species Act of 1973, are prosobranchs (Lysne et al. 2008). Freshwater gastropods in North America reach their greatest diversity in the southeastern United States (Burch 1989). Some of these species reach the western edge of their distributions in the midwestern United States (Leonard 1959, Burch 1989, Hershler 1996, Angelo et al. 2002), including Kansas (Leonard 1959, Angelo et al. 2002). Environmental degradation threatens the continued persistence of peripheral populations of these unique organisms (Angelo et al. 2002).

Call (1885a, b, 1886, 1887) provided the earliest qualitative information on freshwater gastropods in Kansas; basin-specific accounts by Hanna (1909), Franzen (1944), and Branson (1966) followed. Leonard (1959) published the only comprehensive survey of gastropods in the state, with information regarding distribution, life history, and habitat where he documented 22 species of freshwater gastropods in Kansas. Most recently, the Kansas Department of Health and Environment (KDHE) implemented statewide surveys from 1980-2001 to document the distributions of prosobranchs (Angelo et al. 2002).

Leonard (1959) recognized 5 species of prosobranch snails in Kansas. One, *Campeloma crassulum*, is extirpated from the state (Leonard 1959, Angelo et al. 2002). *Cincinnatia integra* is the most widespread species and occurs throughout eastern Kansas, although restricted to few permanent streams (Angelo et al. 2002). *Pomatiopsis lapidaria*, an amphibious prosobranch, is restricted to northeastern Kansas in Muscotah Marsh, Atchison County (Leonard 1959, Angelo et al. 2002). *Pleurocera acuta* is restricted to and occurs in low numbers in the lower Marais des Cynges River and one of its tributaries, Pottawatomie Creek (Leonard 1959, Angelo et al. 2002).

Elimia potosiensis is restricted to Shoal Creek and the Spring River in the Ozarks of southeastern Kansas (Franzen 1944, Leonard 1959, Branson 1966, Angelo et al. 2002).

Probythinella emarginata, historically known only from Pleistocene deposits, was recently added to the list of known extant freshwater gastropods of Kansas. Angelo et al. (2002) collected live specimens of *P. emarginata* in Cedar Creek, Chase County, Kansas in 2001. This stream, in the Neosho River basin, has been consistently ranked among the state's least contaminated and most biologically diverse aquatic systems (Angelo and Cringan 2002).

Three of the 5 species of prosobranch snails in the state are listed as either threatened or endangered by the Kansas Department of Wildlife, Parks, and Tourism (KDWPT). These listed species are *Pl. acuta*, *Po. lapidaria*, and *Pr. emarginata*. Decreased habitat availability due to reduced surface water quality, and quantity, are the justification for concern (Leonard 1959, Angelo et al. 2002). The basic life history attributes of most aquatic gastropods, such as the means of dispersal, habitat preference, and reproductive life histories, are not well adapted to rapid landscape-level changes (Lysne et al. 2008).

Probythinella emarginata is included within the family Hydrobiidae. These minute prosobranchs exhibit life history characteristics that predispose imperilment (Brown et al. 2008). Many hydrobiid species in the western and southeastern United States are documented at only a few isolated springs (Brown et al. 2008). In addition, hydrobiids have been characterized as "poor dispersers" and, consequently, are tightly linked with drainage history (Hershler 1996, Brown et al. 2008). The group contains over 300 recognized species (Hershler 1998), several of which have been added to the federal list of threatened and endangered species; nearly 100 more are candidates for listing.

The paucity of information regarding *P. emarginata* has led to its designation as a threatened species within Kansas. This snail inhabits lotic and lentic inland habitats of the Great Lakes and Mississippi River basin; its distribution ranges from central and southeastern Canada to the central and northeastern United States (Hershler 1996). The small valve (<5 mm long) of *P. emarginata* is smooth, deeply sutured, and, most notably, has a blunt or truncated apex (Hershler 1996). The longevity of *P. emarginata* is unknown, but some prosobranch snails do not live much more than 5 years (Huryn et al. 1994). Additional information is necessary to more adequately assess the conservation status of *P. emarginata*. Basic information on occurrence and distribution in Kansas and habitat requirements are essential to more fully document its conservation status and develop recovery strategies.

Probythinella emarginata is only known from Cedar Creek, but previous paleontological surveys have documented fossil valves of the species in deposits of the ancestral Smoky Hill River in McPherson County, and the ancestral Cimarron River and Crooked Creek in Meade County (Hibbard and Taylor 1960, Miller 1970, Hershler 1996). Fossils also have been collected from the Fall River in the Verdigris River basin in southeastern Kansas (Angelo et al. 2002). The Verdigris River basin is adjacent to the Neosho River basin; the watershed currently supporting the Cedar Creek population of *P. emarginata*. Tiemann and Cummings (2007) suggested intensive sampling efforts of the watersheds of southeastern Kansas to locate populations of prosobranchs that might be undocumented. A survey of Cedar Creek, other streams within the Neosho River basin, and adjacent basins is necessary to accurately describe the current distribution of *P. emarginata* in Kansas.

The objectives of this study were 1) to determine the occurrence and distribution of *P. emarginata* throughout Cedar Creek by sampling available habitats throughout the stream, 2) to survey tributaries and streams in adjacent basins for possible populations of *P. emarginata* in Kansas, 3) to identify habitat associations of *P. emarginata* by quantifying relevant habitat variables, and 4) to document distributions and habitat use of the freshwater gastropod fauna at selected sites in southeastern Kansas. Data associated with these objectives will support a thorough assessment of the conservation status of *P. emarginata* and provide up-to-date information on the freshwater gastropods in the region.

METHODS

Study Area

The Cedar Creek drainage basin, a subbasin of the Neosho River basin, is located in the southwestern quarter of Chase County, Kansas, and encompasses 227 km^2 (Prophet and Ransom 1974). The stream meanders approximately 31 km through the Flint Hills Region and is underlain by Permian shale and limestone of the Chase Group (Prophet and Ransom 1974). Landcover in the basin is estimated to be 74.6% grassland, 21.3% cropland, and 3.5% woodland (KDASC 2008).

Adjacent basins sampled include the Arkansas-Keystone, Walnut, Verdigris, and Neosho. Sites were selected by proximity to Cedar Creek, accessibility, and fish and mussel assemblage similarities with Cedar Creek. Faunal similarity was used as an indirect means of reflecting historical stream connectivity. All samples were collected quantitatively, as described below.

Survey Protocol

I determined site length by calculating the mean of 10 wetted-width measurements taken at 10-m intervals and multiplying the result by 40. Maximum site length was set at 300 m. Each macrohabitat (pool, riffle, and run) in the site was measured in length (m). I selected 15 sample locations in a stratified random manner. This approach ensured that random samples would be collected from all available macrohabitats. The number of samples in each macrohabitat was proportional to the relative length of the site.

There were 60 possible sample locations within each site. The possible locations were placed within the stream channel: ⅓ the stream width from the left and right banks and 10 m in stream length apart. There were 2 possible sample locations every 10 m. Fifteen points, corresponding to macrohabitat length, were randomly selected as sample locations. The design was modified in 2011 to include edge-water habitat by adding 2 points: 1 adjacent to the left bank and 1 adjacent to the right bank. This allowed for 4 possible sample locations every 20 m.

Temperature (°C), salinity (ppm), depth (m), and substrate size were measured for each sample. Temperature and salinity were collected approximately 5 cm above the substrate. Substrate was divided into 7 size categories: fine, sand, fine gravel, coarse gravel, cobble, boulder, and bedrock. I used a large dip net with a 0.2-m^2 frame to collect benthic samples. The frame was perpendicular to the opening of the dip net and defined the area for each sample. I collected gastropods by disturbing the substrate down to 5 cm and brushing the suspended materials into the net. The entire sample, other than large material (i.e., rocks, wood, leaves), was preserved in jars of 70% ethyl alcohol. A subsample was taken when large amounts of sand, silt, and detritus were collected.

I separated the freshwater gastropods from the sample material in the Aquatic Ecology Lab at Fort Hays State University and identified to species. Species identification followed Burch's (1982) key for the freshwater snails of North America. Each specimen was classified as either live or dead; live valves were those with soft bodies still intact or tissue still attached. Dead valves were devoid of soft anatomy.

Species densities were calculated at each site. I used a logistic regression to determine which habitat variables best predicted the presence of *P. emarginata*. Logistic regression was used to determine if other gastropod species demonstrated habitat specificity. Finally, maps depicting the presence of live and dead valves of each species within the study area were produced.

RESULTS

Fifty-two sites were sampled in streams of the Arkansas-Keystone, Walnut, Verdigris, and Neosho basins in southeastern Kansas (Fig. 1, Table 1). Thirteen sites were sampled throughout Cedar Creek, and 21 sites were sampled elsewhere within the upper Neosho River basin. In addition, I surveyed 5 sites in the upper Walnut River basin, 12 sites throughout the Verdigris River basin, and 1 site in Grouse Creek, within the Arkansas-Keystone River basin. Fifteen different gastropod species were collected from the sampling locales. Of these, 11 species were collected live (Table 2), but specimens of *Gyraulus cristae* (Fig. 2), *Promenetus exacuous* (Fig. 3), *P. umbillicatellus* (Fig. 4), and *Valvata bicarinata* (Fig. 5) were only represented by dead shells. No previous records exist for *G. cristae* and *V. bicarinata* in Kansas; each was represented only by 1 subfossil valve. Live individuals were represented by 2 prosobranch and nine pulmonate species.

Prosobranchs

Probythinella emarginata was collected in the Neosho and Verdigris river basins and live individuals were collected at 4 sites or 7.7% of the survey sites (Fig. 6). Live individuals were collected at 2 sites in the downstream portion of Cedar Creek (CC), Chase County and 2 sites in the lower Elk River (ER), Montgomery County. *Probythinella emarginata* was the most common valve collected in Cedar Creek (n = 604) but only 2 live individuals were documented. Live individuals were collected at equal densities of 0.3/m^2 within sites CC6 and CC12P (Table 2). Most of the valves were collected in the lower reaches of Cedar Creek (Fig. 7). Eighty-four *P. emarginata* were collected in the Elk River. Densities within this population varied from 3.7/m^2 within site

ER to 24.2 /m^2 within site ER3. These 2 sites were adjacent to each other and were dominated by algae-covered bedrock. No live individuals were collected upstream or downstream of the bedrock. The presence of *P. emarginata* in the Elk River was negatively associated with edge-water habitat (Wald = 5.891, df = 1, *P* = 0.015) and occurred most often within the river channel. The presence of *P. emarginata* in the Elk River also was associated with higher levels of dissolved oxygen (Wald = 5.786, df = 1, *P* = 0.016). The sample size of *P. emarginata* in Cedar Creek was insufficient to quantify specific habitat associations.

Cincinnatia integra was collected in all 4 river basins, and live individuals were collected at 4 sites or 7.7% of the sites in the survey (Fig. 8). Only weathered and relic valves were collected in the Neosho and Walnut river basins. Live individuals were collected in Grouse Creek, Cowley County; the North Branch Verdigris River, Chase County; the Verdigris River, Greenwood County; and the lower Elk River, Montgomery County. One-hundred-seventeen *C. integra* were collected in Grouse Creek at a density of 38.8/m^2 (Table 2). Eight individuals were collected at site NBV (Tables 1 and 2) in the North Branch Verdigris River at a density of 2.5/m^2; one-hundred were collected in the Verdigris River at a density of 33.3/m^2; one-hundred-twenty-five were collected in the Elk River at densities of 18.7/m^2 within site ER and 23.0/m^2 within site ER3. The presence of *C. integra* was negatively associated with depth (Wald = 3.883, df = 1, *P* = 0.049), therefore, the species generally occurred in shallow water. The presence of *C. integra* also was associated with higher levels of salinity (Wald = 3.942, df = 1, *P* = 0.047) and dissolved oxygen (Wald = 4.351, df = 1, *P* = 0.037).

Pulmonates

Physa sp. (Physidae or physids) were collected in all 4 river basins and live individuals were collected at 47 sites or 90.4% of the survey sites (Fig. 9). These were the dominant species inhabiting edge-water habitat in the survey. The physids were collected at densities of $0.3/m^2$ to $531.7/m^2$ (Table 2). The latter density was recorded at site NBV in the North Branch Verdigris River, Chase County. This reach was characterized by an open canopy, shallow water, and an extensive growth of filamentous-green algae. The presence of physids was positively associated with edge-water habitat (Wald = 26.855, df = 1, P= 0.000) and shallow depths (Wald = 23.473, df = 1, P = 0.000).

Pond snails (Lymnaeidae) were represented in the survey by *Fossaria parva*, *F. bulimoides cockerelli*, *F. obrussa*, and *F. humilis*. In general, live collections of pond snails were few and of low densities. These species were collected in the smallest streams and headwater reaches. Live individuals of *F. parva* were collected at 9 sites or 17.3% of the survey sites (Fig. 10) but occurred in low densities ($0.3/m^2$ to $2.0/m^2$; Table 2). *Fossaria obrussa* was collected at 4 sites or 7.7% of the survey sites (Fig. 11) and occurred at higher densities ($0.3/m^2$ to $29.0/m^2$; Table 2). *Fossaria bulimoides cockerelli* was collected only at 1 site (CCHN) or 1.9% of survey sites (Fig. 12) and occurred at a density of $14.5/m^2$ (Table 2). This was the most upstream site surveyed on Cedar Creek, Chase County, and had intermittent water flow. The reach was characterized by an open canopy, shallow water, and macrophytes. *Fossaria bulimoides cockerelli* was the only species of pond snail with significant habitat associations, and its presence was negatively associated with depth (Wald = 5.446, df = 1, P = 0.020) and temperature

(Wald = 7.155, df = 1, *P* = 0.007). *Fossaria humilis* was collected only at 1 site (BC) or 1.9% of the survey sites and was represented by a single individual (Fig. 13).

Limpets (Ancylidae) were represented in the survey by *Ferissia kirklandi*. This species was collected in headwater streams of the Neosho, Verdigris, and Walnut river basins. Only dead valves were collected in Grouse Creek, in the Arkansas-Keystone basin. The species was collected at 10 sites or 19.2% of survey sites (Fig. 14). *Ferissia kirklandi* tightly adheres to rocks, leaves, and wood; consequently, individuals might have been overlooked relative to other species while processing samples in the field. *Ferissia kirklandi* was collected at densities of 0.3/m^2 to 2.0/m^2 (Table 2) and occurred too irregularly to discern habitat associations.

The planorbids (Planorbidae) were represented in the survey by live individuals of *Menetus dilatatus*, *Gyraulus parvus*, and *Helisoma trivolvis*. *Menetus dilatatus* was collected in all 4 river basins, and live individuals were collected in 19 sites or 36.5% of the survey sites (Fig. 15) at densities of 0.3/m^2 to 46.6/m^2 (Table 2). The presence of *M. dilatatus* was negatively associated with salinity (Wald = 5.531, df = 1, *P* = 0.019) and positively associated with dissolved oxygen (Wald = 4.428, df = 1, *P* = 0.035). *Gyraulus parvus* was collected in the Neosho and Verdigris river basins, but live individuals were collected only from site ER3 in the Elk River, Montgomery County (Fig. 16) at a density of 8.7/m^2 (Table 2). *Helisoma trivolvis* was collected in all 4 river basins, however live individuals only were collected at 4 sites or 7.7% of the survey sites (Fig. 17). *Helisoma trivolvis* was collected at densities of 0.3/m^2 at sites CC8, DCS, and ER to 0.5/m^2 at site CCHN (Table 2). *Gyraulus parvus* and *H. trivolvis*, poorly represented in the survey, exhibited no significant habitat associations.

DISCUSSION

Prosobranchs

The 2 species of prosobranch gastropods (*P. emarginata* and *C. integra*) were collected at 7 (13.5%) of the survey sites. These species were restricted to larger, more permanent streams within the study area; none were collected in headwaters. The Elk River, Montgomery County, was the only locality that supported both *P. emarginata* and *C. integra*. They were further restricted to sites ER and ER3 in the lower portion of the river, just 6 miles upstream of Elk City Reservoir; neither species was collected in the upstream portion of the river. The Elk River is only 1 of 2 streams in Kansas known to support more than 1 species of prosobranch gastropod. The other, Pottawatomie Creek, Franklin County, supports *P. acuta* and *C. integra*.

Probythinella emarginata was known to occur only in Cedar Creek, Chase County. The species in Cedar Creek, as judged by previous collections by the KDHE (Angelo et al. 2002) and Fort Hays State University (Sowards and Stark, unpublished data), was more abundant and common in the lower portion of the stream in 2001. Sowards and Stark (unpublished data) collected more than 200 live individuals of *P. emarginata* in Cedar Creek shortly after the first collection (Angelo et al. 2002). The current survey was conducted throughout Cedar Creek (13 sites), and 7 sites were sampled in its lower portion, however, only 2 live individuals were collected. The paucity of live collections of *P. emarginata* and the disproportionate abundance of dead valves suggests the species has experienced a precipitous decline in its Cedar Creek population. Severe drought conditions in 2006 might be at least partially responsible for the decline.

Drought conditions have varying effects on lotic systems and their associated macroinvertebrate faunas. Drought increases water temperatures (Cowx et al. 1984), sedimentation rates (Kraft 1972, Wood and Petts 1999), and algal densities (Biggs et al. 2005). A prolonged increase in water temperature has negative impacts on some aquatic organisms (Cowx et al. 1984) and decreases dissolved oxygen concentrations (McKee et al. 2003). An increase in algal concentration following drought conditions might not have immediate negative effects on macroinvertebrate communities, but the subsequent bacterial decay results in a depletion of dissolved oxygen above the benthic layer (Fillos and Molof 1972). Additionally, Brown et al. (1998) described prosobranchs as susceptible to high temperatures and hypoxic conditions within stagnant pools during droughts. The presence of *P. emarginata* was positively associated with dissolved oxygen in the Elk River. Therefore, periods of limited dissolved oxygen in Cedar Creek resulting from droughts might have exacerbated their decline.

Drought also reduces dilution of wastewater from cattle operations, agriculture, and wastewater effluent (Chessman and Robinson 1987). There are no wastewater treatment plants in the Cedar Creek watershed, but a number of cattle operations and agricultural fields are present. The most noteworthy toxicant affecting the survival of freshwater mollusks is ammonia (NH_3). Total ammonia concentrations in Cedar Creek are relatively low, but a concentration of 0.53 mg/L was recorded during a high-runoff event in 2010 (KDHE unpublished water quality data). This is well below the water quality standard in Kansas (pH = 7.5, temperature = 12.0°C, total NH_3 = 4.36; Kansas surface water quality standards, http://www.kdheks.gov/water/download/kwqs_plus_supporting.pdf, accessed 8 February

2012) but might be detrimental to some species of freshwater mollusks (Augspurger et al. 2003, Mummert et al. 2003).

Probythinella emarginata was relatively common in the Elk River and collected at densities of 3.7/m^2 and 24.2/m^2 at site ER and ER3, respectively. The species was only collected on a 400-m length of algae-covered bedrock. No individuals were collected in habitats above or below the bedrock, suggesting this habitat is necessary for their survival. *Probythinella emarginata* presence was positively associated with higher levels of dissolved oxygen and negatively associated with edge-water habitat. Fluctuating water levels near the banks are not suitable for most prosobranch species. Seasonal, and often diel, changes in water levels and rapid diel variation in temperature at these edge-water habitats produce an inhospitable environment for prosobranchs. The shallow channel habitat of the Elk River is less variable in temperature and maintains water even during periods of drought.

Site ER2 was located further upstream on the Elk River in Elk County. This site was surveyed south of Howard, Kansas, and no evidence of *P. emarginata* was obtained. Angelo et al. (2002) sampled prosobranch gastropods at 1 site on the Elk River, Montgomery County, during their statewide surveys. This collection site was located approximately 2 miles downstream of the locality currently supporting *P. emarginata*. They collected no *P. emarginata*, which suggests the species is narrowly distributed even within the Elk River.

Weathered and subfossil valves of *P. emarginata* were collected throughout the Neosho River basin and the Verdigris River within the Verdigris River basin (Fig. 6). Fossil valves of *P. emarginata* were collected in the Fall River within the Verdigris River basin and in Pleistocene deposits of historic channels of the Smoky Hill River, Cimarron River, and Crooked Creek in western Kansas. This information suggests the species was historically more widespread throughout the state. Climactic shifts and changes in historical drainage patterns since the Pleistocene and more recent changes in landuse might be responsible for the range contraction of *P. emarginata* in Kansas.

Cincinnatia integra is apparently the most common prosobranch in Kansas and occurs in permanent streams throughout the eastern half of the state. During this survey, live populations of the species were documented at 4 previously unknown localities. Angelo et al. (2002) collected *C. integra* in the Neosho and Walnut river basins, but I was unable to collect live individuals in these basins. Only weathered and subfossil valves were collected in the upper Neosho and Walnut river basins. All collections of live *C. integra* within the study area were collected in permanent streams within the Verdigris River basin and Grouse Creek within the Arkansas-Keystone River basin.

Leonard (1959) described *C. integra* as inhabiting quiet waters on mud substrates or "ooze-covered gravel bottoms". I collected the species on a variety of substrates and detected no significant association. *Cincinnatia integra* was negatively associated with depth and was collected most often in shallow, edge-water habitats but only in permanent streams with more stable conditions. The species also was positively associated with dissolved oxygen and salinity. Similar to *P. emarginata* and other species of prosobranchs, a positive association with dissolved oxygen was not surprising. Salinity, the NaCl concentration in the water, varied little within the study area. *Cincinnatia integra* was abundant at site VR on the Verdigris River. This site had relatively high levels of salinity and probably resulted in a biased statistical association. The species was present in the lower Elk River sites with minimal (0.1 ppt) salinity values.

Pulmonates

Pulmonates, consisting of 9 different species, were relatively common and collected at 48 sites or 92.3% of the survey sites. These sites included a broad variety of habitats within springs, headwaters, and larger streams.

The physids (Physidae), represented by *Physa* sp., were the dominant species in the survey. They were collected in various habitats and stream sizes and associated with edge-water habitats of shallow depths, which are characterized by fluctuating temperatures and water levels. Von Brand et al. (1950) demonstrated physids were less tolerant compared to species of Planorbidae and prosobranchs when oxygen is depleted for more than 62 hours, and aerial respiration is not possible. This illustrates the association of physids to shallow, edge-water habitats where immediate access to aerial respiration is possible.

Physid dominance in the region can be explained by stream intermittence, drought, and landuse. The majority of the streams in the survey were smaller, temporary streams characteristic of pulmonate species habitat. Drought conditions in 2011 were characterized by low water levels and increased temperatures — conditions more suitable for physids. Landuse in the region varied, but observations of bank encroachment by fields, riparian tree removal near bridges, and occasional streamside feedlots were noted. Chadwick et al. (2006) described physids as replacing the formerly dominant shredders in streams with altered landuse. Removal of riparian area, increased runoff from urban areas, agricultural fields, and feedlots subsequently increase primary productivity of stream systems. These conditions increase the available food supply for freshwater gastropods, but decrease the quality of water necessary for species of prosobranchs. Physid species have the necessary physiological adaptations to persist in headwater streams, during drought conditions in otherwise permanent streams, and in degraded aquatic systems. Therefore, habitat preferences, coupled with life-history strategy of rapid, semelparous reproduction allows physids to dominate and occur in high densities in southeastern Kansas.

Pond snails (Lymnaeidae), represented by *F. parva*, *F. obrussa*, *F. humilis*, and *F. b. cockerelli*, were encountered at 30.8% of the survey sites. They were collected in springs, headwaters, and small streams throughout the survey. Pond snails are cosmopolitan in distribution (Burch 1989) and are some of the first colonizers of pond habitats and temporary streams with recent flow events (Dillon et al. 2006). Pond snails were collected in low densities, with the exception of 2 headwater sites with temporary flow that contained high densities of *F. obrussa* and *F. b. cockerelli*. *Fossaria parva* was the only freshwater gastropod present at Miller Spring, Marion County — a cold water spring that flows into Cedar Creek, Chase County. *Fossaria bulimoides cockerelli* was collected in a temporary headwater habitat in the upstream portion of Cedar Creek, and was negatively associated with depth and temperature. This species, like most pulmonates, inhabits shallow water with access to aerial respiration. The site was characterized by high summer temperatures, and *F. b. cockerelli* presence might have been associated with cooler microhabitats that minimize respiratory stress.

The limpets (Ancylidae), represented in the survey by *F. kirklandi*, were collected at 19.2% of the survey sites. They were collected in a variety of substrates and stream types from headwaters to larger streams. This species has secondarily derived gills and is not capable of aerial respiration (Brown et al. 1998). Dillon et al. (2006) described limpets as inhabiting cooler, well-oxygenated streams of northern latitudes, which might explain the low abundances and densities encountered during the survey.

The planorbids (Planorbidae), represented in the survey by *M. dilatatus*, *G. parvus*, and *H. trivolvis*, were collected at 42.3% of the survey sites in a variety of substrates and stream types. *Menetus dilatatus* was the most common planorbid and was encountered most often in larger streams. This species was negatively associated with salinity. This is due to the high abundance of live individuals collected within the Elk River, Montgomery County, where salinity was consistently low. *Menetus dilatatus* also was positively associated with dissolved oxygen. Planorbids rely on cutaneous respiration and have dedicated respiratory pigments for gas exchange (Brown et al. 1998) and, similar to limpets and prosobranchs, are more adversely affected by changes in water quality that might lessen the available concentration of oxygen dissolved in the water. *Gyraulus parvus* was collected at 1 site in the Elk River. This species is generally collected in lacustrine environments but is commonly collected in streams on aquatic vegetation (Dillon et al. 2006). This site on the Elk River was characterized by filamentous-green algae that provided habitat for *G. parvus*.

Helisoma trivolvis was only represented by 6 live individuals and is not well adapted to lotic environments (Dillon et al. 2006). The species generally is restricted to lacustrine habitats of ponds, marshes, and wetlands. These environments were not sampled during this survey.

CONCLUSIONS

Kansas represents the western range of the majority of its native prosobranch gastropods (Leonard 1959, Hershler 1996, Angelo et al. 2002). Natural barriers composed of a westward gradient of reduced precipitation and stream flows limit the distribution of these obligate aquatic species to the eastern half of Kansas. Prosobranchs in Kansas are further limited in distribution to permanent streams with minimal variation in water quality and quantity. In southeastern Kansas, in particular, prosobranchs are rare and have limited distributions, while pulmonates, less affected by habitat alteration, are ubiquitous.

Probythinella emarginata was more widely distributed in Kansas during the Pleistocene epoch. However, due to changes in climate and stream drainage patterns, and recent habitat alteration, the range has since retracted to a few locations in southeastern Kansas. Occurrence in southeastern Kansas apparently is relegated to Cedar Creek, Chase County, and the Elk River, Montgomery County. *Probythinella emarginata* populations in these rivers are further restricted to downstream segments with stable flows and greater dissolved oxygen concentrations. The population in Cedar Creek is not only limited spatially but has undergone a significant decline since its first collection in 2001. Drought conditions in 2006 and the associated effects on water quality might be at least partially responsible for the decline.

Probythinella emarginata was common and collected in 60% of the samples at 1 locality in the lower Elk River. The species was collected within the stream channel and was negatively associated with edge-water habitat. Live individuals were collected on bedrock substrate, and further sampling within the Elk River that targets this habitat might result in additional specimens.

The restricted occurrence of *P. emarginata* in Kansas and the natural constraints (i.e., recent droughts) that might influence its remaining habitat emphasize the vulnerability of the species to local extirpation. The historic range retraction, habitat restrictions, and pronounced decline of the Cedar Creek population, warrant a downgrade of the conservation status of *P. emarginata* to “Endangered Species” in Kansas.

RECOVERY INITIATIVES

Based on the range retraction, habitat restrictions, and decline of the Cedar Creek population of *P. emarginata*, the species should be considered an "Endangered Species" in Kansas. A recovery plan that attempts to upgrade the conservation status of *P. emarginata* in the state should include 1) additional surveys, 2) population monitoring, 3) propagation research, 4) relocation and propagation monitoring, and 5) a conservation status reevaluation.

Additional surveys

I collected evidence for *P. emarginata* in the Verdigris and Neosho river basins. Additionally, the Marais des Cygnes, lower Neosho, and Spring river basins harbor high molluscan diversity and might contain populations of *P. emarginata*. Surveys that target the occurrence of *P. emarginata* should be focused in the Verdigris, Marais des Cygnes, Spring, and lower Neosho river basins. These surveys should be focused in permanent streams that have the highest dissolved oxygen concentrations as judged by water quality information provided by the KDHE. I suggest investigators should target microhabitats of larger substrates and dense aquatic vegetation within these reaches. Similarly, stream reaches downstream of groundwater inputs also might provide suitable habitat and should be surveyed for additional populations of *P. emarginata*.

Population monitoring

An assessment of recruitment of the population in the Elk River would provide valuable baseline information for managing this population. It will be important to monitor the dynamics of this population over consecutive years to determine the important biotic and abiotic parameters that affect the survival and recruitment of *P.*

emarginata. A research design, similar to the methods of this survey, should be standardized over time and space; therefore, allowing managers to determine the stability or stochastic nature of this population. If the population of *P. emarginata* remains stable, individuals within this stream reach could be relocated to other rivers in Kansas. I would suggest relocation only in areas where live or recently dead individuals of *P. emarginata* were collected: the lower portion of Cedar Creek, Chase County and the lower portion of Bills Creek, Chase County.

Propagation research

Information regarding an understanding of the reproductive biology of *P. emarginata* would be necessary for propagation. If the population size of *P. emarginata* in the Elk River is stable and large enough for propagation, then individuals should be propagated from this population. Finally, *P. emarginata* should be transplanted to permanent streams with high concentrations of dissolved oxygen and high densities of aquatic vegetation throughout its range in southeastern Kansas.

Relocation and propagation monitoring

Given the small population size, research on the success of relocation and propagation attempts might be necessary to recover the species in Kansas. Managers should monitor the populations that resulted from relocation and propagation attempts with methods similar to population monitoring in the Elk River. The results of this research would determine the overall feasibility of these recovery strategies and provide opportunities for other species in the future.

Conservation status reevaluation

The overall objective of these recovery initiatives is to provide the basis for a recovery plan that addresses range expansion and population protection and limits the probability for the extirpation of *P. emarginata* in Kansas. Managers should evaluate the conservation status of *P. emarginata* after the completion of each objective indicated above. This will allow managers to determine the success of these and other future initiatives towards minimizing the likelihood of extirpation of the species in Kansas.

LITERATURE CITED

Aldridge, D. W. 1983. Physiological ecology of freshwater prosobranchs. Pages 329-358 in: The Mollusca, Vol.6, Ecology. W. D. Russell-Hunter, editor. Academic Press, Orlando, Florida.

Angelo, R. T., and M. S. Cringan. 2002. Delta hydrobe: a newly discovered snail in Kansas. Kansas Pearly Mussel Newsline 7:3.

Angelo, R. T., M. S. Cringan, and J. E. Fry. 2002. Distributional revisions and new and amended occurrence records for prosobranch snails in Kansas. Transactions of the Kansas Academy of Science 105:246-257.

Augspurger, T., A. E. Keller, M. C. Black, W. G. Cope, and F. J. Dwyer. 2003. Water quality guidance for protection of freshwater mussels (Unionidae) from ammonia exposure. Environmental Toxicology and Chemistry 22:2569-2575.

Biggs, B. J. F., V. I. Nikora, and T. H. Snelder. 2005. Linking scales of flow variability to lotic ecosystem structure and function. River Research and Applications 21:283-298.

Boycott, A. E. 1936. The habits of freshwater Mollusca in Britain. Journal of Animal Ecology 5:116-186.

Branson, B. A. 1966. A partial biological survey of the Spring River drainage in Kansas, Oklahoma and Missouri. Part I. Collecting sites, basic limnological data, and mollusks. Transactions of the Kansas Academy of Science 69:242-293.

Brown, K. M. 1983. Do life history tactics exist at the intraspecific level: data from freshwater snails. American Naturalist 121:871-879.

Brown, K. M. 1998. The role in shell strength in selective foraging by crayfish for gastropod prey. Freshwater Biology 40:355-360.

Brown, K. M. 2001. Mollusca: Gastropoda. Pages 297-329 in: Ecology and classification of North American freshwater invertebrates. J. H. Thorp and A. P. Covich, editors. Academic Press, San Diego, California.

Brown, K. M., J. E. Alexander, and J. H. Thorp. 1998. Differences in the ecology and distribution of lotic pulmonate and prosobranch gastropods. American Malacological Bulletin 14:91-101.

Brown, K. M., B. Lang, and K. E. Perez. 2008. The conservation ecology of North American pleurocerid and hydrobiid gastropods. Journal of the North American Benthological Society 27:484-495.

Burch, J. B. 1982. Freshwater snails (Mollusca: Gastropoda) of North America. U.S. Environmental Protection Agency Publication 600/3-82-026. 365 pp.

Burch, J. B. 1989. North American freshwater snails: introduction, systematics, nomenclature, identification, morphology, habitats, distribution. Walkerana 2:1-80.

Call, R. E. 1885a. Contributions to a knowledge of the fresh-water Mollusca of Kansas. II. Fresh-water univalves. Bulletin of Washburn College Laboratory of Natural History 1:51-54.

Call, R. E. 1885b. Contributions to a knowledge of the fresh-water Mollusca of Kansas. IV. Bulletin of Washburn College Laboratory of Natural History 1:115-124.

Call, R. E. 1886. Fifth contribution to a knowledge of the fresh-water Mollusca of Kansas. Bulletin of Washburn College Laboratory of Natural History 1:177-184.

Call, R. E. 1887. Sixth contribution to a knowledge of the fresh-water Mollusca of Kansas. Bulletin of Washburn College Laboratory of Natural History 2:11-25.

Chadwick, M. A., D. R. Dobberfuhl, A. C. Benke, A. D. Huryn, K. Suberkropp, and J. E. Thiele. 2006. Urbanization affects stream ecosystem function by altering hydrology, chemistry, and biotic richness. Ecological Applications 16:1796-1807.

Chessman, B. C., and D. P. Robinson. 1987. Some effects of the 1982-83 drought on water quality and macroinvertebrate fauna in the lower LaTrobe River, Victoria. Australian Journal of Marine and Freshwater Research 38:289-299.

Cowx, I. G., W. O. Young, and J. M. Hellawell. 1984. The influence of drought on the fish and invertebrate populations of an upland stream in Wales. Freshwater Biology 14:165-177.

Davis, G. M. 1982. Historical and ecological factors in the evolution, adaptive radiation, and biogeography of freshwater mollusks. American Zoologist 22:375-395.

Dillon, R. T., Jr., B. T. Watson, and T. W. Stewart. 2006. The freshwater gastropods of North America. Internet address: http://www.fwgna.org accessed 5 February 2012.

Fillos, J., and A. H. Molof. 1972. Effect of benthal deposits on oxygen and nutrient economy of flowing waters. Water Pollution Control Federation 44:644-662.

Franzen, D. S. 1944. New state records of Mollusca from Kansas. Transactions of the Kansas Academy of Science 47:261-273.

Hanna, G. D. 1909. Mollusca of Douglas County, Kansas. Nautilus 23:81-82; 94-96.

Hershler, R. 1996. Review of the North American aquatic snail genus *Probythinella* (Rissooidea: Hydrobiidae). Invertebrate Biology 115:120-144.

Hershler, R. 1998. A systematic review of the hydrobiid snails (Gastropoda: Rissooidea) of the Great Basin, western United States. Part I. Genus *Pyrgulopsis*. Veliger 41:1-132.

Hibbard, C. W., and D. W. Taylor. 1960. Two late Pleistocene faunas from southwestern Kansas. Contributions to the University of Michigan Museum of Paleontology 16:1-223.

Huryn, A. D., J. W. Koebel, and A. C. Benke. 1994. Life history and longevity of the pleurocerid snail *Elimia*: a comparative study of eight populations. Journal of North American Benthological Society 13:540-556.

Jenkinson, J. J., and R. M. Todd. 1998. Management of native mollusk resources. Pages 283-305 in: Aquatic Fauna in Peril: the Southeastern Perspective. G. W. Benz and D. E. Collins, editors. Aquatic Research Institute Special Publication 1, Chattanooga, Tennessee.

Kansas Data Access and Support Center (KDASC). 2008. 1990 Kansas landcover patterns map updated. Kansas Data Access and Support Center, Lawrence, Kansas. Internet address: http://www.kansasgis.org/catalog/index.cfm accessed on 2 February 2011.

Kraft, M. E. 1972. Effects of controlled flow reduction on a trout stream. Journal of the Fisheries Research Board of Canada 29:1405-1411.

Leonard, A. B. 1959. Handbook of gastropods in Kansas. University of Kansas Museum of Natural History. Miscellaneous Publication No. 20. 224 pp.

Lydeard, C., R. H. Cowie, W. F. Ponder, A. E. Bogan, P. Bouchet, S. A. Clark, K. S. Cummings, T. J. Frest, O. Gargominy, D. G. Herbert, R. Hershler, K. E. Perez, B.

Roth, M. Seddon, E. E. Strong, and F. G. Thompson. 2004. The global decline of nonmarine mollusks. BioScience 54:321-330.

Lysne, S. J., K. E. Perez, K. M. Brown, R. L. Minton, and J. D. Sides. 2008. A review of freshwater gastropod conservation: challenges and opportunities. Journal of the North American Benthological Society 27:463-470.

McKee, D., D. Atkinson, S. E. Collings, J. W. Eaton, A. B. Gill, I. Harvey, K. Hatton, T. Heyes, D. Wilson, and B. Moss. 2003. Response of freshwater microcosm communities to nutrients, fish, and elevated temperature during winter and summer. Limnology and Oceanography 48:707-722.

McMahon, R. F. 1983. Physiological ecology of freshwater pulmonates. Pages 359-430 in: The Mollusca, Vol. 6, Ecology. W. D. Russell-Hunter, editor. Academic Press, Orlando, Florida.

Miller, B. B. 1970. The Sandahl molluscan fauna (Illinoian) from McPherson County, Kansas. Ohio Journal of Science 70:39-50.

Mummert, A. K., R. J. Neves, T. J. Newcomb, and D. S. Cherry. 2003. Sensitivity of juvenile freshwater mussels (*Lampsilis fasciola*, *Villosa iris*) to total, and unionized ammonia. Environmental Toxicology and Chemistry 22:2545-2553.

NatureServe. 2007. NatureServe explorer: an online encyclopedia of life. Version 6.1. NatureServe, Arlington, Virginia. Internet address: http://www.natureserve.org/explorer.

Neves, R. J., A. E. Bogan, J. D. Williams, S. A. Ahlstedt, and P. W. Hartfield. 1997. Status of aquatic mollusks in the southeastern United States: A downward spiral of diversity. Pages 43-85 in: Aquatic fauna in peril: The southeastern perspective.

Special Publication No. 1, Southeast Aquatic Research Institute. G. W. Benz and D. E. Colllins, editors. Lenz Design & Communications, Decatur, Georgia.

Newbold, J. D., J. W. Elwood, R. V. O'Neill, and A. L. Sheldon. 1983. Phosphorus dynamics in a woodland stream ecosystem: A study of nutrient spiralling. Ecology 64:1249-1265.

Palmieri, M. D., J. R. Palmieri, and J. T. Sullivan. 1980. A chemical analysis of the habitat of nine commonly occurring Malaysian freshwater snails. Malayan Naturalist Journal 34:39-45.

Prophet, C. W., and J. D. Ransom. 1974. Summer stream metabolism values for Cedar Creek, Kansas. Southwestern Naturalist 19:305-308.

Richardson, T. D., J. F. Scheiring, and K. M. Brown. 1988. Secondary production of two long lived lotic gastropods (Pleuroceridae: *Elimia*). Journal of the North American Benthological Society 7:234-241.

Rosemond, A. D., P. J. Mullholland, and J. W. Ellwood. 1993. Top-down and bottom-up control of stream periphyton: effects of nutrients and herbivores. Ecology 74:1264-1280.

Russell-Hunter, W. D. 1978. Ecology of freshwater pulmonates. Pages 335-383 in: The Pulmonates, Vol. 2A, Systematics, Evolution and Ecology. V. Fretter and J. Peak, editors. Academic Press, Orlando, Florida.

Tiemann, J. S., and K. S. Cummings. 2007. Newly recognized distribution records for two pleurocerids (Gastropoda) in Kansas. Transactions of the Kansas Academy of Science 110:268-271.

Von Brand, T., H. D. Baernstein, and B. Mehlman. 1950. Studies on the anaerobic metabolism and the aerobic carbohydrate consumption of some fresh water snails. Biological Bulletin 98:266-276.

Wood, P. J., and G. E. Petts. 1999. The influence of drought on chalk stream macroinvertebrates. Hydrological Processes 13:387-399.

TABLE 1. Survey locations for freshwater gastropods in the Neosho, Verdigris, Arkansas-Keystone (AKB), and Walnut river basins during the summers of 2010 and 2011.

Site	Stream	County	Date	Latitude	Longitude
BACH	Bachelor Creek	Greenwood	June 2011	37.83289	-96.10300
BC	Bills Creek	Chase	June 2011	38.14408	-96.79831
Can2	Caney River	Chautauqua	October 2011	37.29327	-96.46439
CC10	Cedar Creek	Chase	July 2010	38.21803	-96.83273
CC11	Cedar Creek	Chase	September 2010	38.14680	-96.77270
CC12P	Cedar Creek	Chase	October 2010	38.22508	-96.83425
CC13	Cedar Creek	Chase	October 2010	38.24540	-96.80803
CC3	Cedar Creek	Chase	June 2010	38.19192	-96.81957
CC4	Cedar Creek	Chase	June 2010	38.16762	-96.72372
CC5	Cedar Creek	Chase	June 2010	38.22610	-96.83087
CC6	Cedar Creek	Chase	June 2010	38.22603	-96.83497
CC7	Cedar Creek	Chase	June 2010	38.22458	-96.83375
CC8	Cedar Creek	Chase	June 2010	38.16845	-96.72963
CC9	Cedar Creek	Chase	July 2010	38.22017	-96.83197
CCDS	Cedar Creek	Chase	June 2010	38.19297	-96.82018
CCHN	Cedar Creek	Chase	May 2010	38.16083	-96.71278
CnC1	Coon Creek	Chase	June 2011	38.23095	-96.80786
CnC2	Coon Creek	Chase	June 2011	38.22069	-96.80387
Cole	Cole Creek	Butler	July 2011	37.95530	-96.77605
CR1	Cottonwood River	Marion	July 2011	38.28551	-97.00313
CRCV	Caney River	Chautauqua	October 2011	37.11097	-96.48930
CyC	Coyne Creek	Chase	June 2011	38.27513	-96.73766
DCS	Diamond Springs	Morris	May 2011	38.61577	-96.76289
DIAM	Diamond Creek	Chase	June 2011	38.39914	-96.63651
Doy	Doyle Creek	Marion	June 2011	38.23509	-96.92525
Doy2	Doyle Creek	Marion	July 2011	38.22401	-96.94387
ER	Elk River	Montgomery	October 2011	37.27298	-95.91975
ER2	Elk River	Elk	October 2011	37.45551	-96.25465
ER3	Elk River	Montgomery	October 2011	37.27730	-95.92584
FR	Fall River	Greenwood	June 2011	37.76839	-96.21571
Grouse	Grouse Creek	Cowley	October 2011	37.10633	-96.82223
MC	Middle Creek	Chase	June 2011	38.38641	-96.67950
Mcan	Middle Caney	Montgomery	October 2011	37.02608	-95.95610
MS	Miller Spring	Marion	May 2011	38.20879	-96.84401
NBV	North Branch Verdigris	Chase	June 2011	38.18513	-96.37519
NC	North Cottonwood	Marion	June 2011	38.50495	-97.29240
NNC	No Name	Marion	May 2011	38.23043	-96.89577
NRNR	Neosho River	Lyon	October 2011	38.36727	-96.00137
PC	Prather Creek	Chase	May 2011	38.37296	-96.57684

TABLE 1. (continued)

Site	Stream	County	Date	Latitude	Longitude
SCot	South Cottonwood	Marion	June 2011	38.34634	-97.08803
SFC1	South Fork Cottonwood	Chase	June 2011	38.13193	-96.54619
SCF	Spring Creek	Marion	June 2011	38.22367	-96.93669
SFC2	South Fork Cottonwood	Chase	June 2011	38.26292	-96.53178
TCRM	Turkey Creek	Chase	June 2011	38.18430	-96.82307
TCSC	Turkey Creek	Chase	May 2010	38.16880	-96.83103
VR	Verdigris River	Greenwood	June 2011	38.08447	-96.05091
VRAS	Verdigris River	Wilson	October 2011	37.38400	-95.66924
Waln	Walnut River	Butler	July 2011	37.98569	-96.74017
WBF	West Branch Fall River	Greenwood	June 2011	37.87578	-96.39893
WBW	West Branch Whitewater	Butler	July 2011	37.81644	-97.06254
White	Whitewater River	Butler	July 2011	37.76598	-97.01299
WW	West Branch Walnut	Butler	July 2011	37.86817	-96.85301

TABLE 2. Freshwater gastropods collected from the Neosho, Verdigris, Arkansas-Keystone (AKB), and Walnut river basins. Numbers refer to density (#/m^2) of live individuals.

	Neosho River Basin									
Species / Sites:	BC	CC3	CC4	CC5	CC6	CC7	CC8	CC9	CC10	CC11
Prosobranchs										
Cincinnatia integra	–	–	–	–	–	–	–	–	–	–
Probythinella emarginata	–	–	–	–	0.33	–	–	–	–	–
Pulmonates										
Ferissia kirklandi	–	–	–	–	–	–	–	–	–	–
Fossaria bulimoides cockerelli	–	–	–	–	–	–	–	–	–	–
Fossaria humilis	0.33	–	–	–	–	–	–	–	–	–
Fossaria obrussa	–	–	–	–	–	–	–	–	–	–
Fossaria parva	1.00	–	–	–	–	–	–	–	–	–
Gyraulus parvus	–	–	–	–	–	–	–	–	–	–
Helisoma trivolvis	–	–	–	–	–	–	0.33	–	–	–
Menetus dilatatus	–	–	–	0.33	–	–	–	–	–	–
Physa sp.	89.58	1.33	3.67	0.67	–	–	0.67	1.33	3.67	10.00

TABLE 2. (continued)

	Neosho River Basin									
Species / Sites:	CC12P	CC13	CCDS	CCHN	CnC1	CnC2	CR1	CyC	DCS	DIAM
Prosobranchs										
Cincinnatia integra	–	–	–	–	–	–	–	–	–	–
Probythinella emarginata	0.33	–	–	–	–	–	–	–	–	–
Pulmonates										
Ferissia kirklandi	–	–	–	–	–	–	–	0.33	–	–
Fossaria bulimoides cockerelli	–	–	–	14.50	–	–	–	–	–	–
Fossaria humilis	–	–	–	–	–	–	–	–	–	–
Fossaria obrussa	–	–	–	–	–	–	–	0.33	–	–
Fossaria parva	–	–	–	–	1.00	–	–	–	0.33	–
Gyraulus parvus	–	–	–	–	–	–	–	–	–	–
Helisoma trivolvis	–	–	–	0.50	–	–	–	–	0.33	–
Menetus dilatatus	–	–	–	–	9.33	12.15	–	–	–	–
Physa sp.	27.00	0.33	0.33	10.00	103.00	195.88	67.33	48.67	3.67	6.67

TABLE 2. (continued)

	Neosho River Basin									
Species / Sites:	Doy	Doy2	MC	MCan	MS	NC	NNC	NRNR	PC	SCF
Prosobranchs										
Cincinnatia integra	–	–	–	–	–	–	–	–	–	–
Probythinella emarginata	–	–	–	–	–	–	–	–	–	–
Pulmonates										
Ferissia kirklandi	–	–	0.89	–	–	0.67	–	–	0.67	–
Fossaria bulimoides cockerelli	–	–	–	–	–	–	–	–	–	–
Fossaria humilis	–	–	–	–	–	–	–	–	–	–
Fossaria obrussa	–	–	–	–	–	–	–	–	–	–
Fossaria parva	–	–	–	–	1.00	0.33	0.67	–	2.00	–
Gyraulus parvus	–	–	–	–	–	–	–	–	–	–
Helisoma trivolvis	–	–	–	–	–	–	–	–	–	–
Menetus dilatatus	–	–	–	3.33	–	–	–	–	2.00	0.33
Physa sp.	14.72	30.67	40.67	1.83	–	78.37	338.67	166.00	105.56	10.78

TABLE 2. (continued)

Species	Sites: Scot	SFC1	SFC2	TCRM	TCSC	BACH	Can2	CRCV	ER	ER2
	Neosho River Basin					Verdigris River Basin				
Prosobranchs										
Cincinnatia integra	–	–	–	–	–	–	–	–	18.67	–
Probythinella emarginata	–	–	–	–	–	–	–	–	3.67	–
Pulmonates										
Ferissia kirklandi	–	–	–	–	–	–	–	–	–	–
Fossaria bulimoides cockerelli	–	–	–	–	–	–	–	–	–	–
Fossaria humilis	–	–	–	–	–	–	–	–	–	–
Fossaria obrussa	–	0.33	–	0.67	–	–	–	–	–	–
Fossaria parva	–	–	–	–	–	0.67	–	–	–	–
Gyraulus parvus	–	–	–	–	–	–	–	–	–	–
Helisoma trivolvis	–	–	–	–	–	–	–	–	0.33	–
Menetus dilatatus	–	1.33	–	0.53	–	0.33	0.67	0.67	1.67	1.00
Physa sp.	531.70	119.89	2.67	162.16	0.33	3.67	16.78	139.33	155.44	4.00

TABLE 2. (continued)

	Verdigris River Basin					AKB	Walnut River Basin			
Species / Sites:	ER3	FR	NBV	VR	VRAS	Grouse	Cole	Waln	WBF	WBW
Prosobranchs										
Cincinnatia integra	23.00	–	2.50	33.33	–	38.83	–	–	–	–
Probythinella emarginata	24.17	–	–	–	–	–	–	–	–	–
Pulmonates										
Ferissia kirklandi	0.67	–	–	–	0.33	–	0.33	0.67	–	1.33
Fossaria bulimoides cockerelli	–	–	–	–	–	–	–	–	–	–
Fossaria humilis	–	–	–	–	–	–	–	–	–	–
Fossaria obrussa	–	–	29.00	–	–	–	–	–	–	–
Fossaria parva	–	–	–	–	–	–	0.33	–	–	–
Gyraulus parvus	8.67	–	–	–	–	–	–	–	–	–
Helisoma trivolvis	–	–	–	–	0.33	–	–	–	–	–
Menetus dilatatus	46.58	0.67	–	–	0.33	0.33	0.33	–	0.33	–
Physa sp.	78.58	47.00	291.50	1.67	334.33	6.00	1.67	58.11	6.00	30.63

TABLE 2. (continued)

	Walnut River Basin	
Species — Sites:	White	WW
Prosobranchs		
Cincinnatia integra	–	–
Probythinella emarginata	–	–
Pulmonates		
Ferissia kirklandi	–	2.00
Fossaria bulimoides cockerelli	–	–
Fossaria humilis	–	–
Fossaria obrussa	–	–
Fossaria parva	–	–
Gyraulus parvus	–	–
Helisoma trivolvis	–	–
Menetus dilatatus	–	–
Physa sp.	2.33	8.00

FIGURE 1. Collection sites in the Arkansas-Keystone, Neosho, Verdigris, and Walnut river basins.

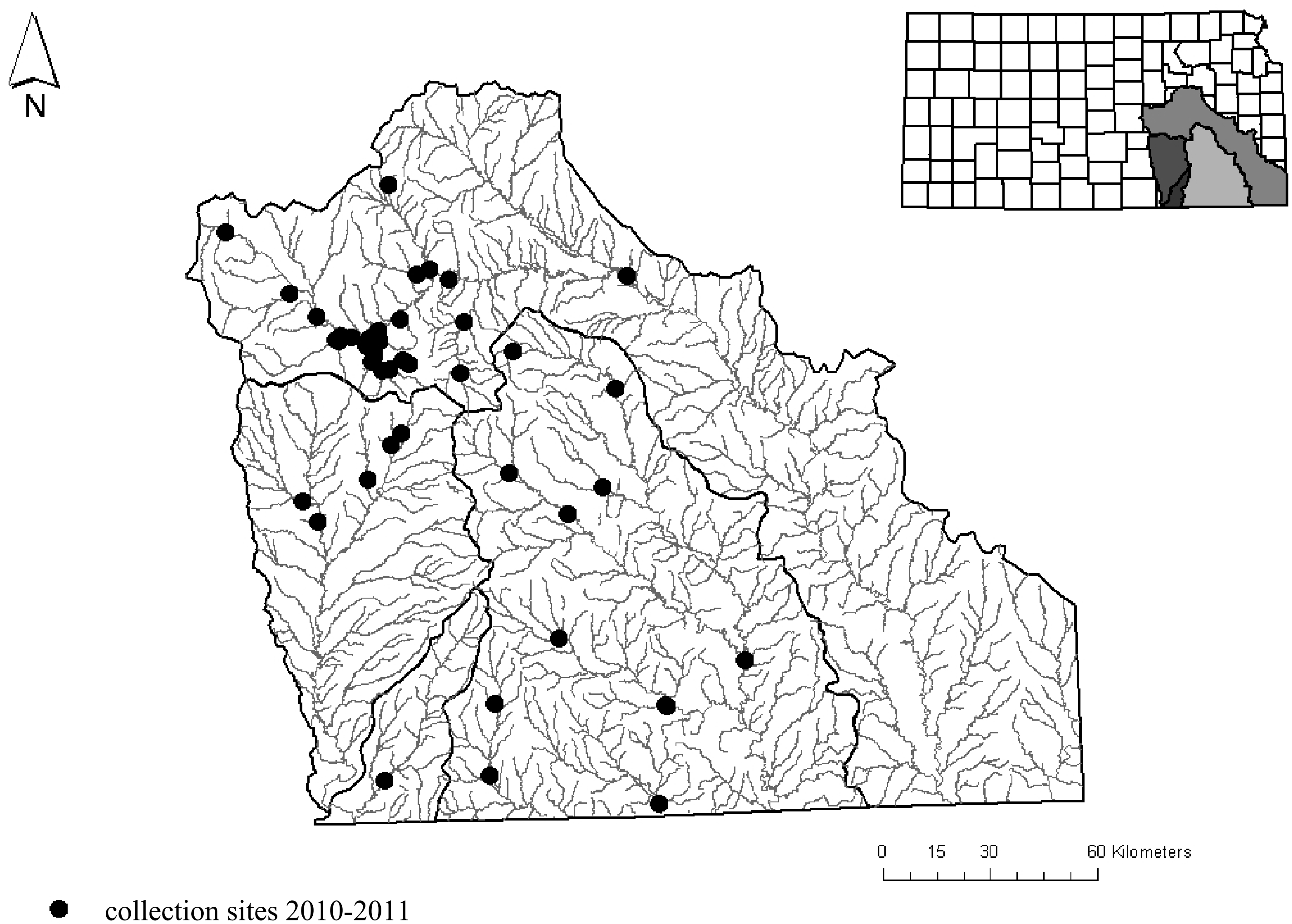


FIGURE 2. *Gyraulus cristae* collection sites in the Arkansas-Keystone, Neosho, Verdigris, and Walnut river basins.

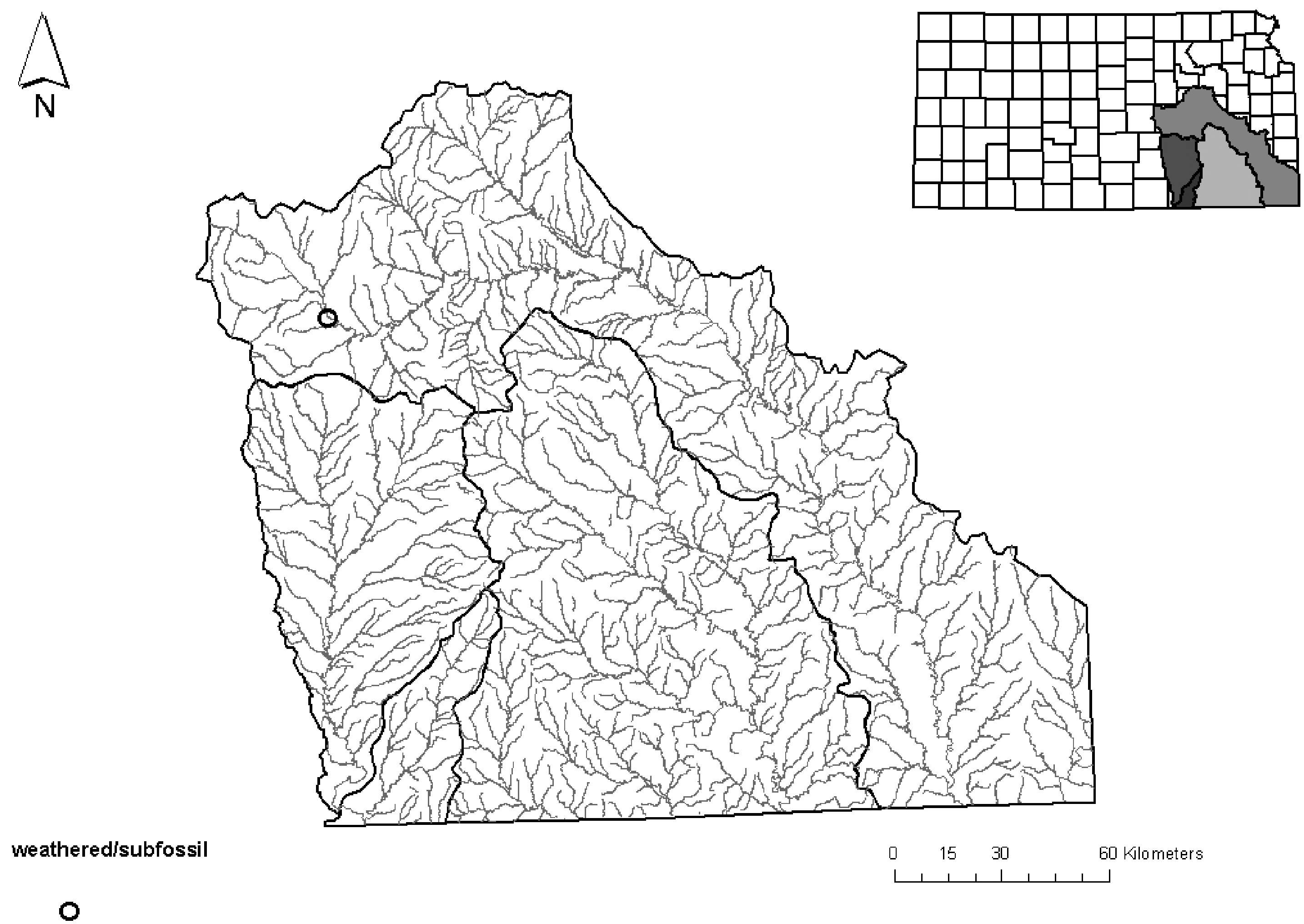


FIGURE 3. *Promenetus exacuous* collection sites in the Arkansas-Keystone, Neosho, Verdigris, and Walnut river basins.

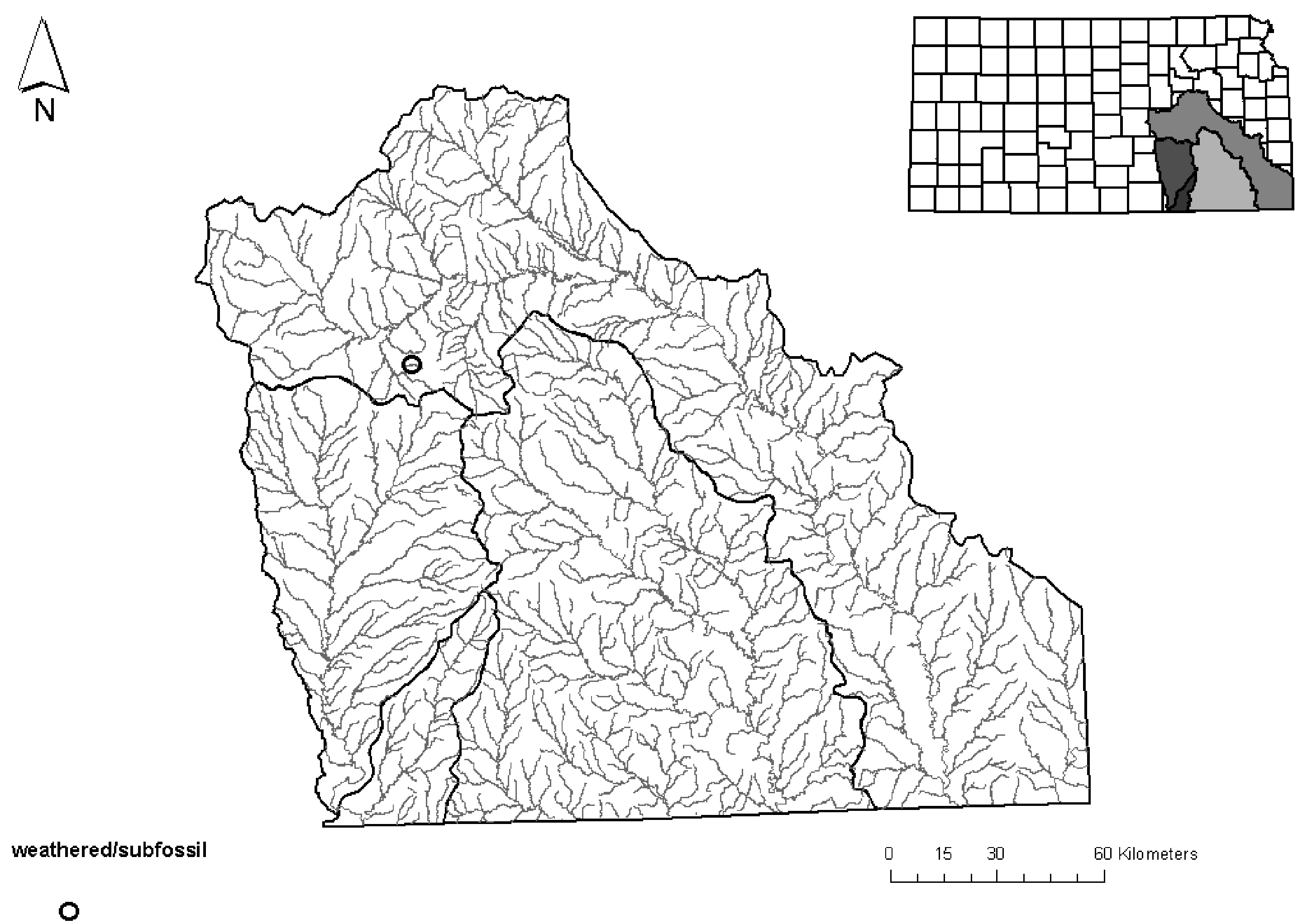


FIGURE 4. *Promenetus umbillicatellus* collection sites in the Arkansas-Keystone, Neosho, Verdigris, and Walnut river basins.

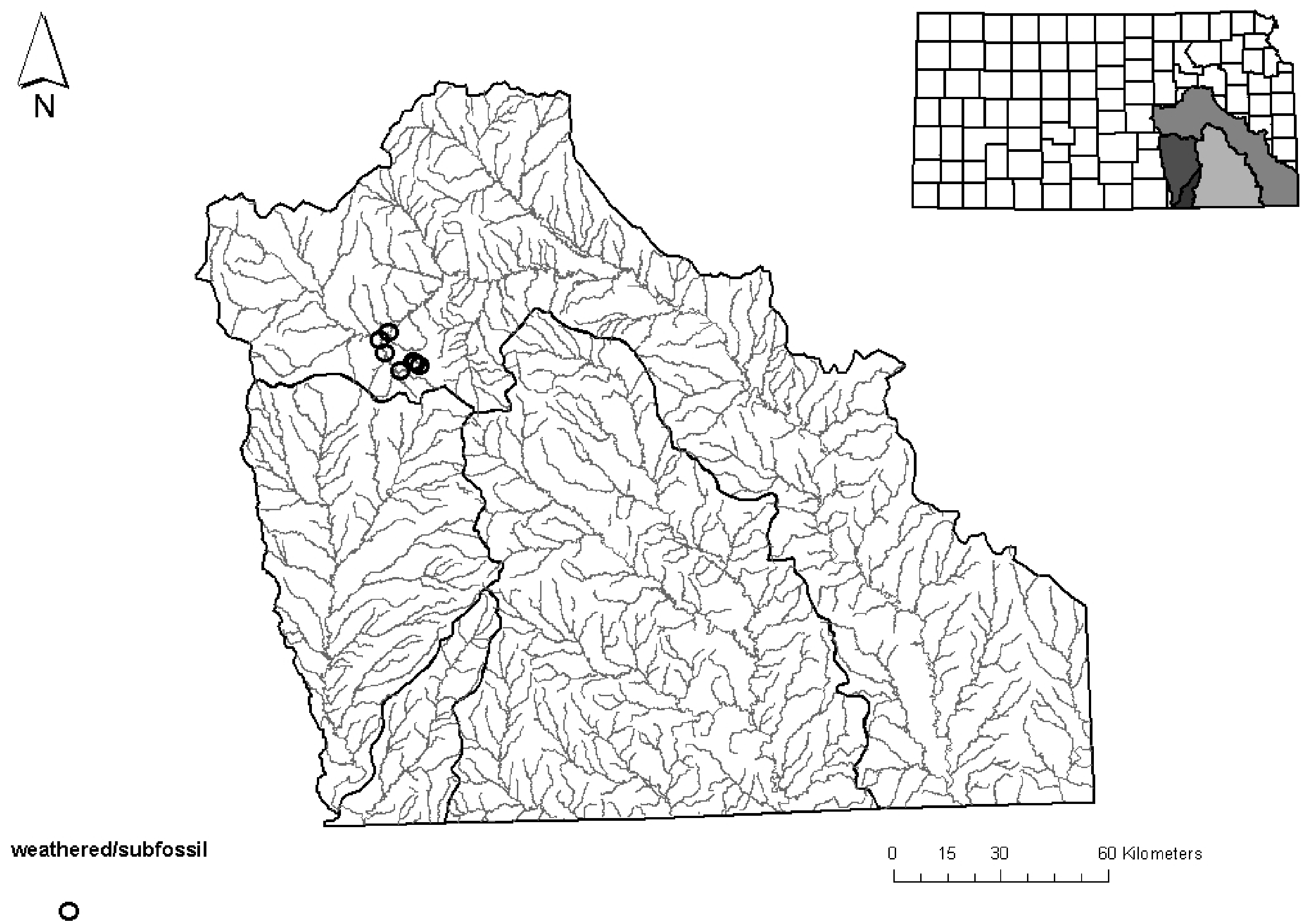


FIGURE 5. *Valvata bicarinata* collection sites in the Arkansas-Keystone, Neosho, Verdigris, and Walnut river basins.

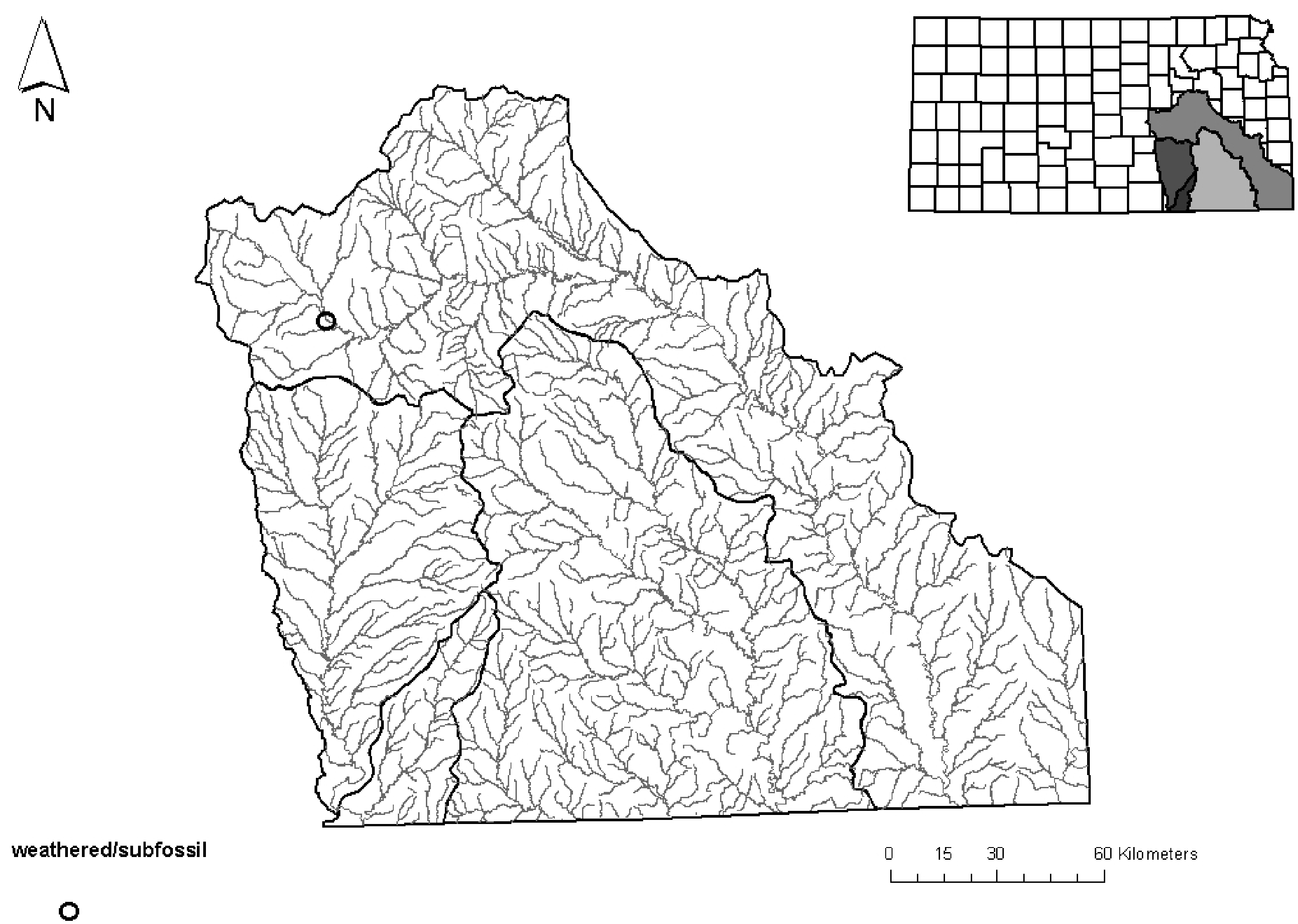


FIGURE 6. *Probythinella emarginata* collection sites in the Arkansas-Keystone, Neosho, Verdigris, and Walnut river basins.

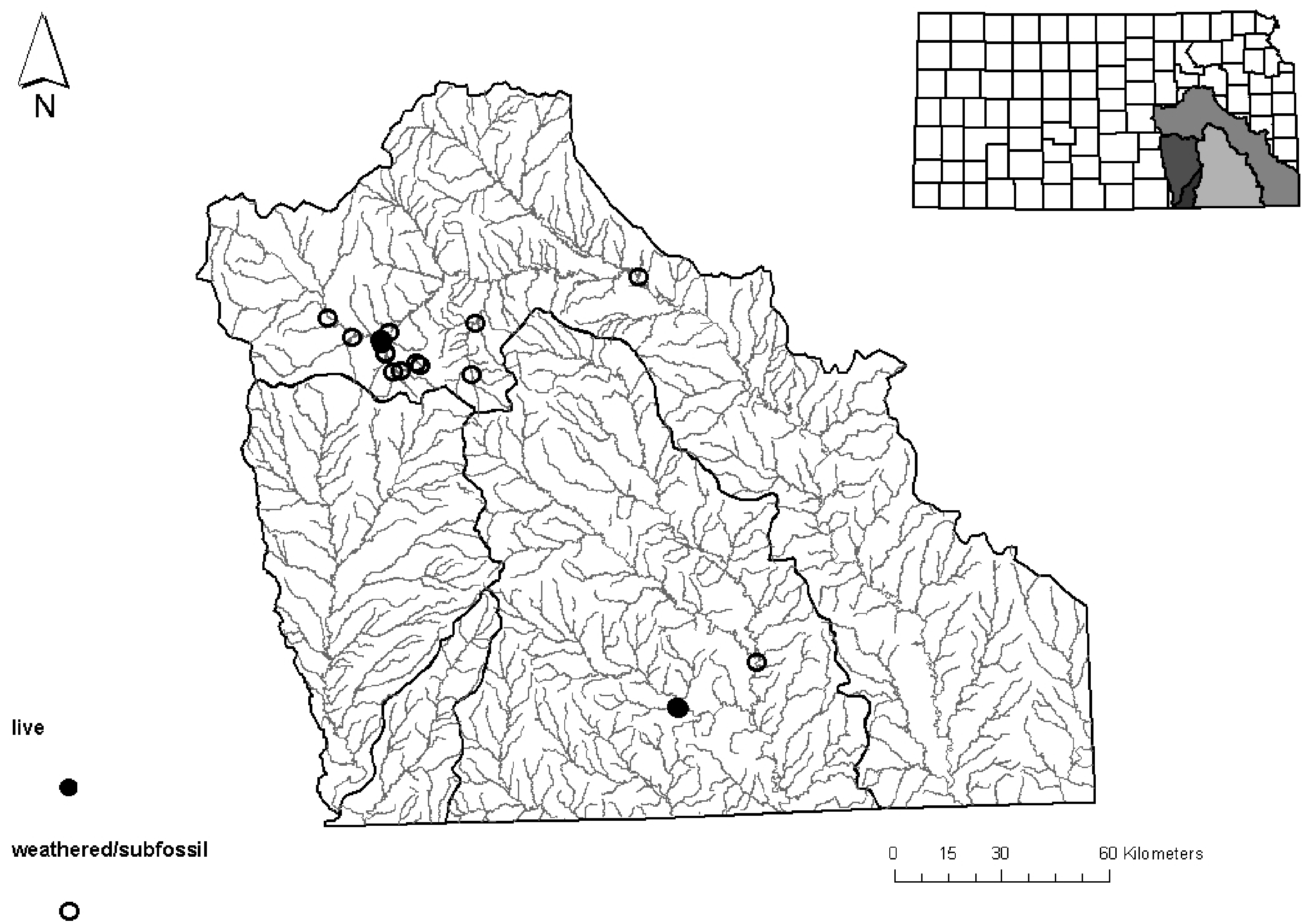


FIGURE 7. *Probythinella emarginata* abundance at collection sites in Cedar Creek, Chase County, Kansas.

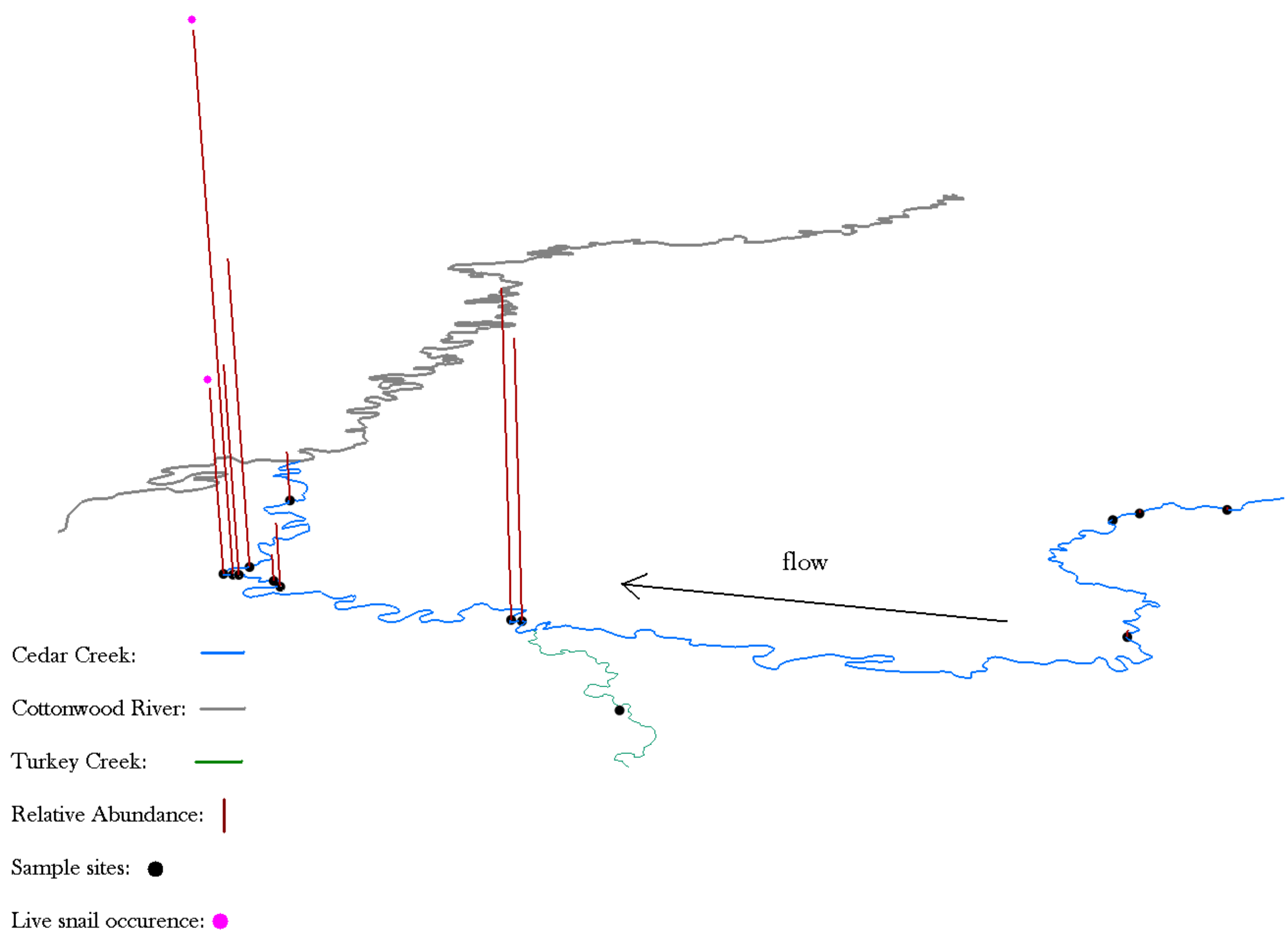


Figure 8. *Cincinnatia integra* collection sites in the Arkansas-Keystone, Neosho, Verdigris, and Walnut river basins.

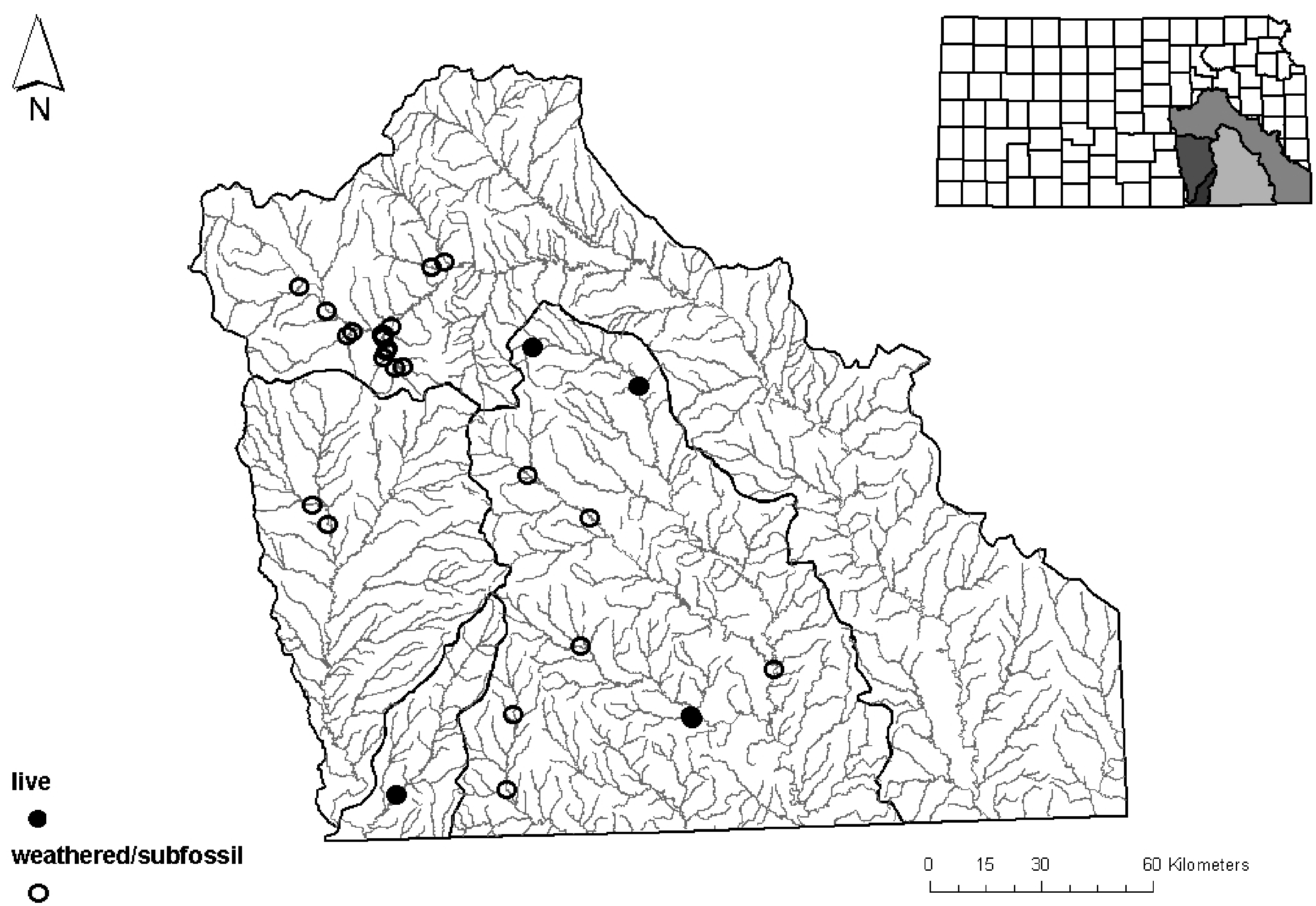


FIGURE 9. *Physa* sp. collection sites in the Arkansas-Keystone, Neosho, Verdigris, and Walnut river basins.

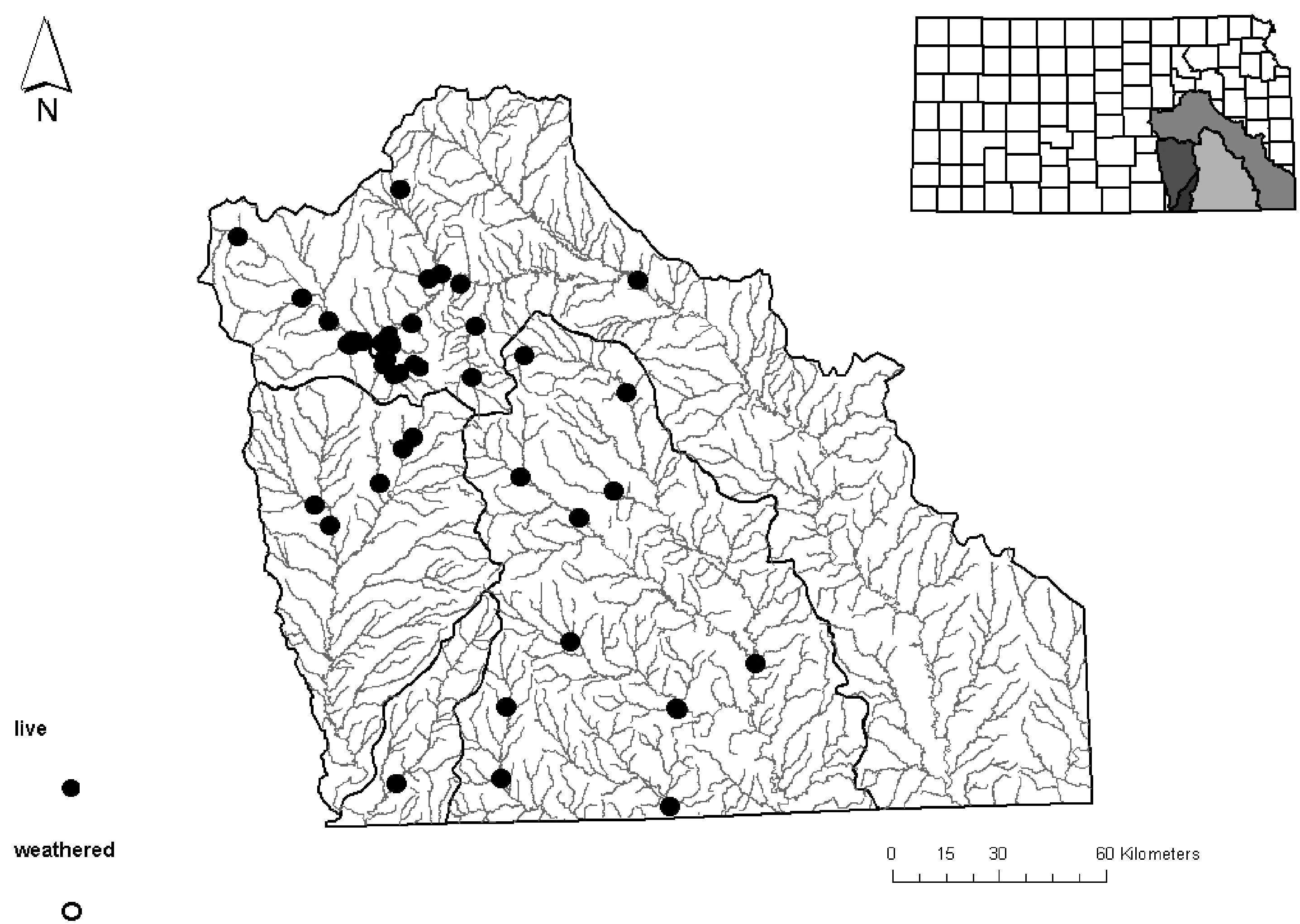


FIGURE 10. *Fossaria parva* collection sites in the Arkansas-Keystone, Neosho, Verdigris, and Walnut river basins.

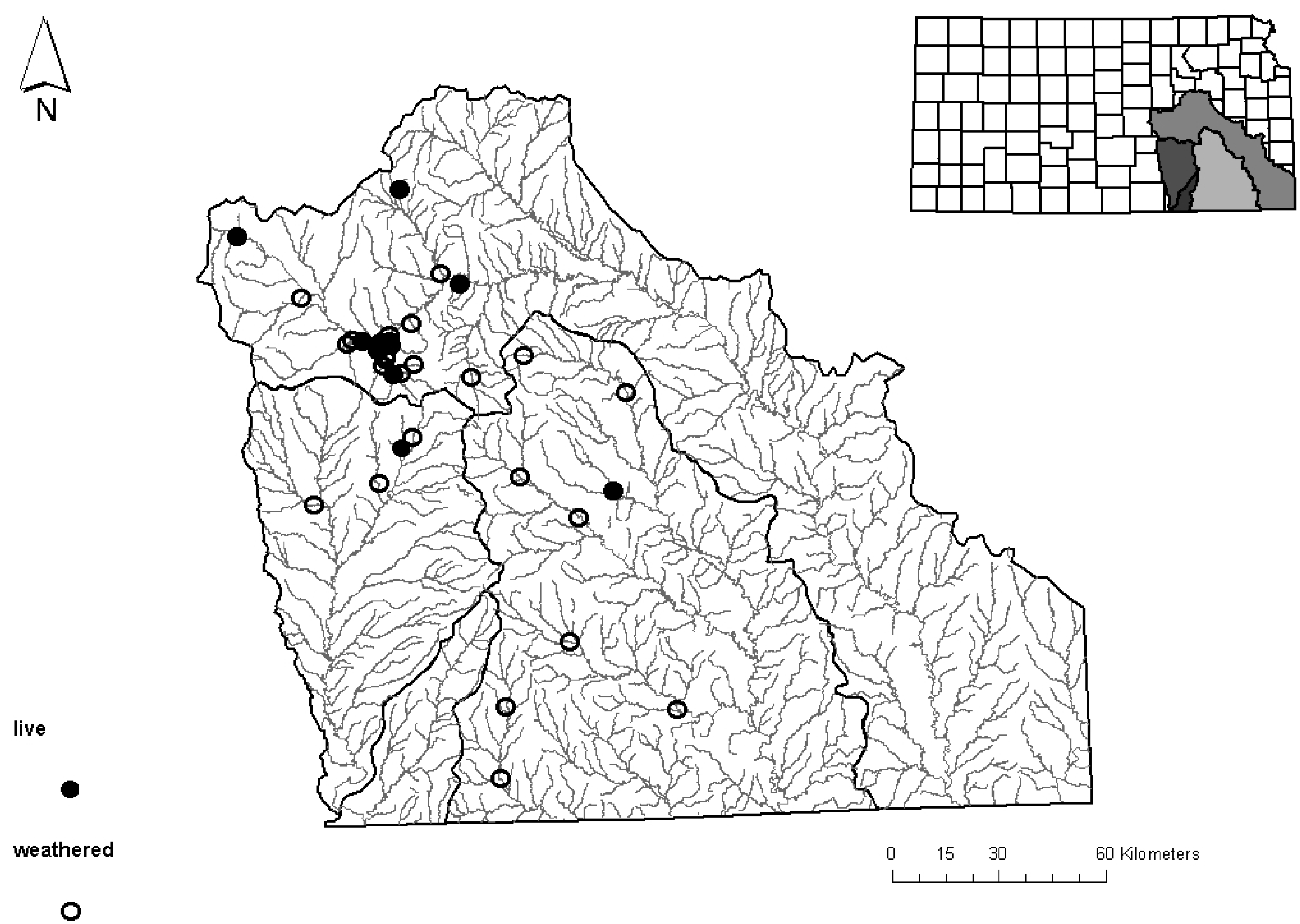


FIGURE 11. *Fossaria obrussa* collection sites in the Arkansas-Keystone, Neosho, Verdigris, and Walnut river basins.

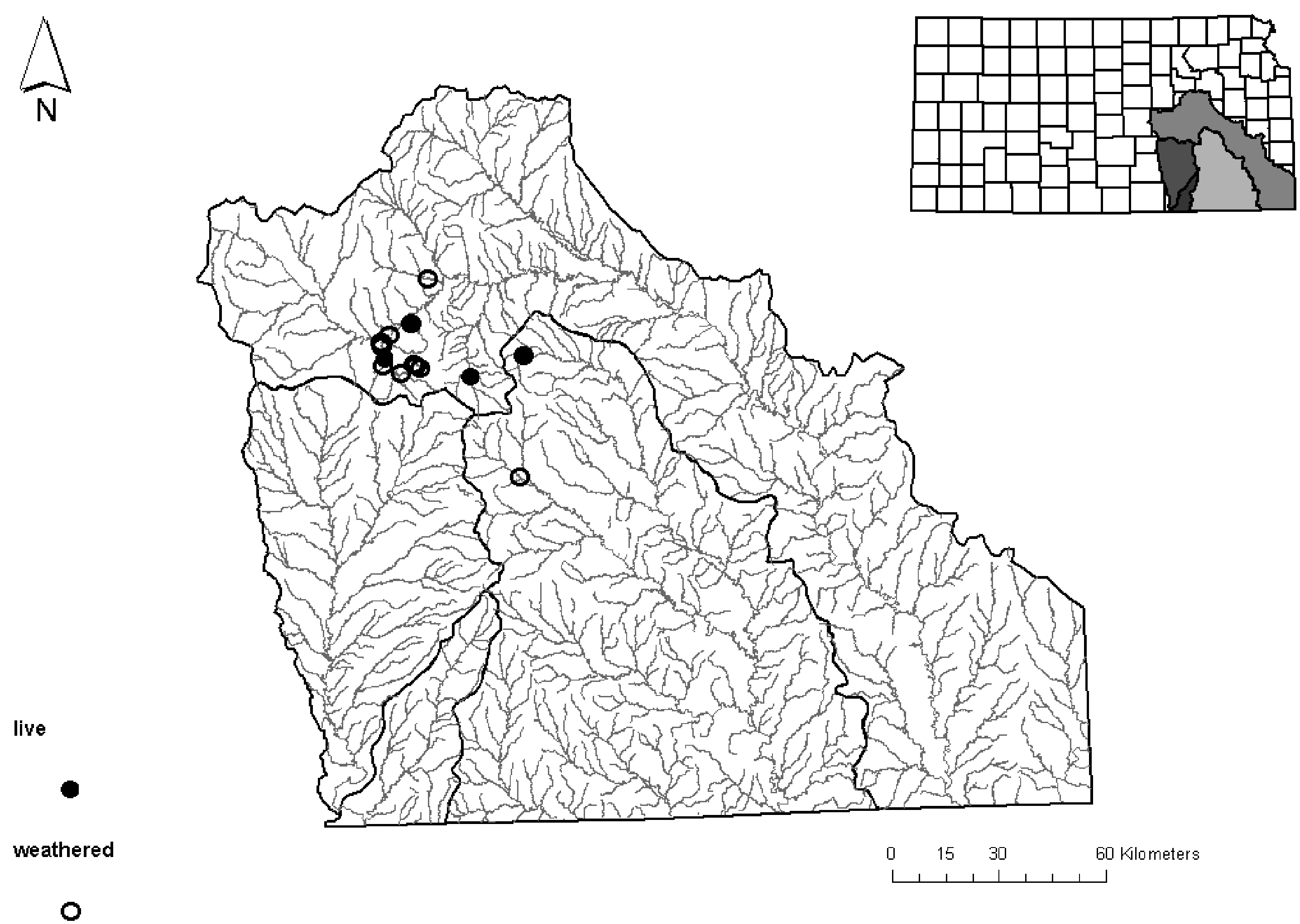


FIGURE 12. *Fossaria bulimoides cockerelli* collection sites in the Arkansas-Keystone, Neosho, Verdigris, and Walnut river basins.

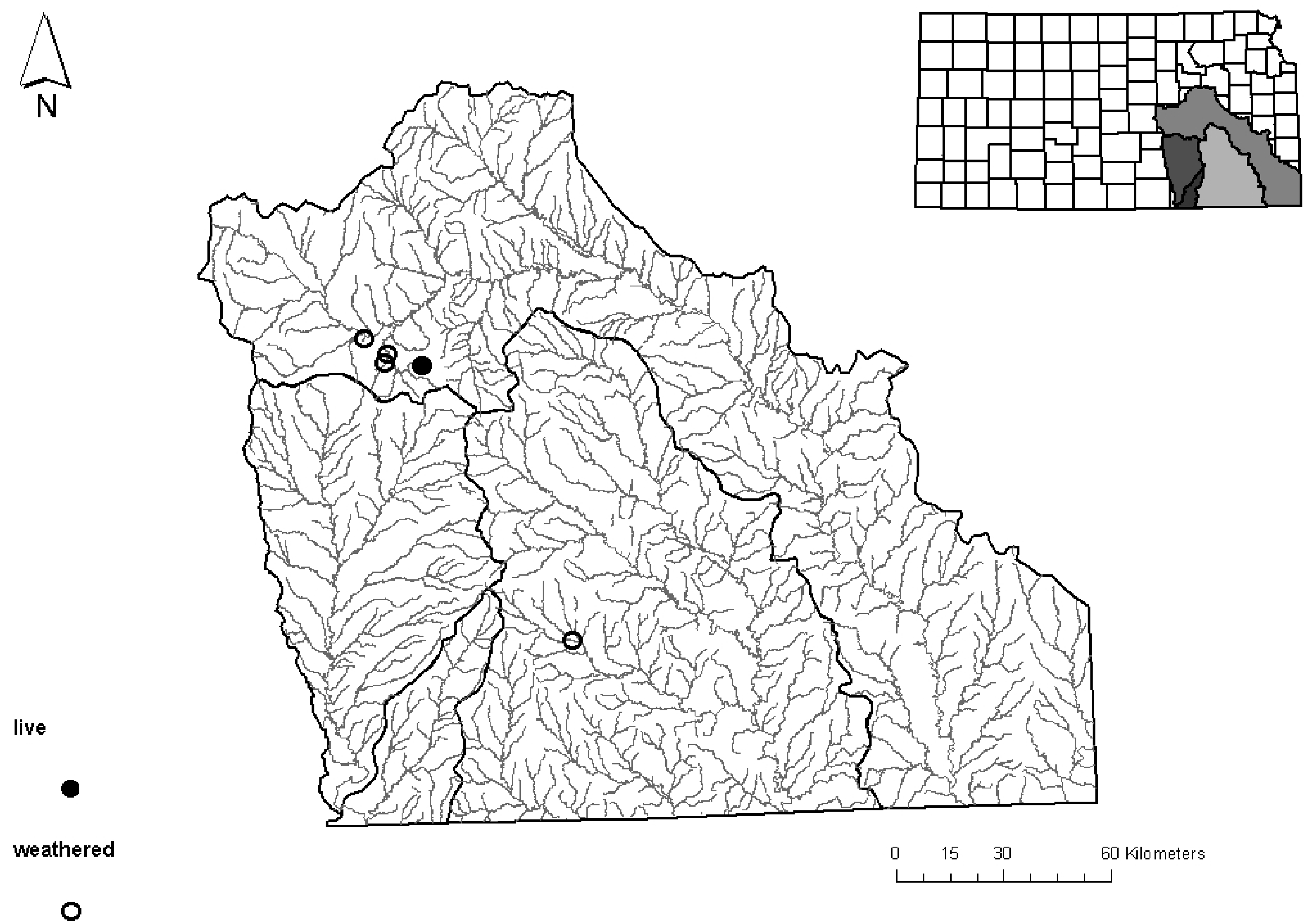


FIGURE 13. *Fossaria humilis* collection sites in the Arkansas-Keystone, Neosho, Verdigris, and Walnut river basins.

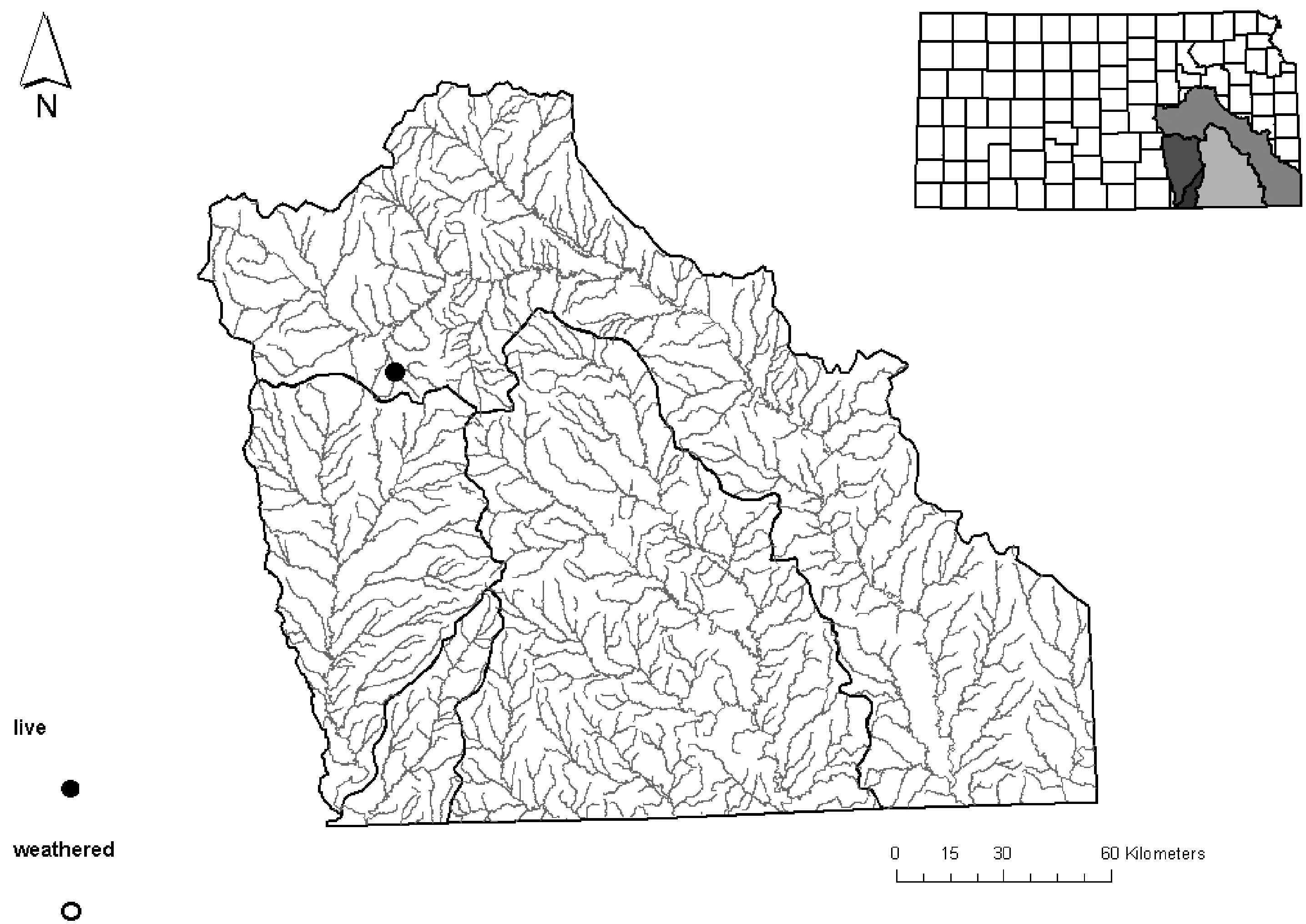


FIGURE 14. *Ferissia kirklandi* collection sites in the Arkansas-Keystone, Neosho, Verdigris, and Walnut river basins.

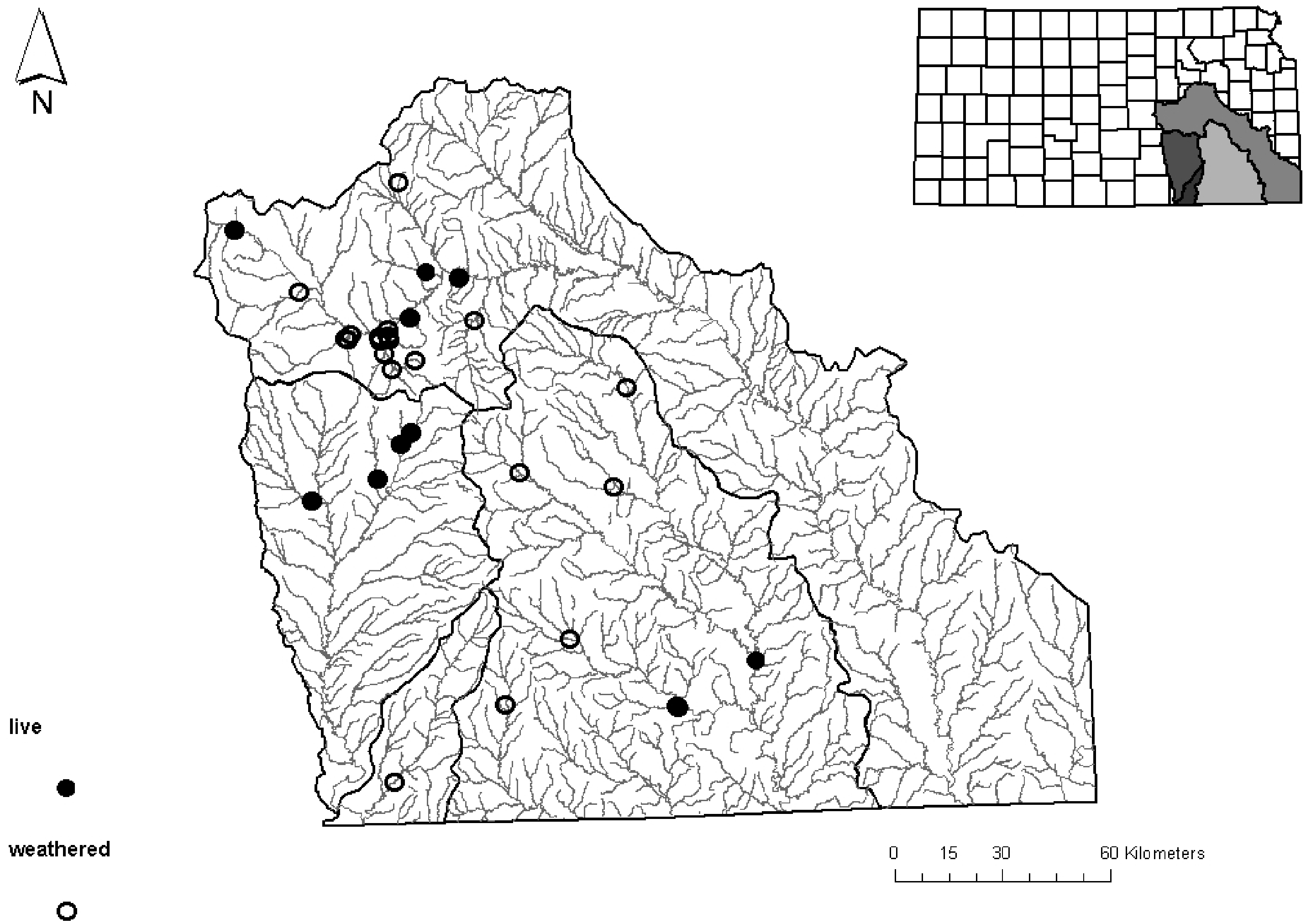


FIGURE 15. *Menetus dilatatus* collection sites in the Arkansas-Keystone, Neosho, Verdigris, and Walnut river basins.

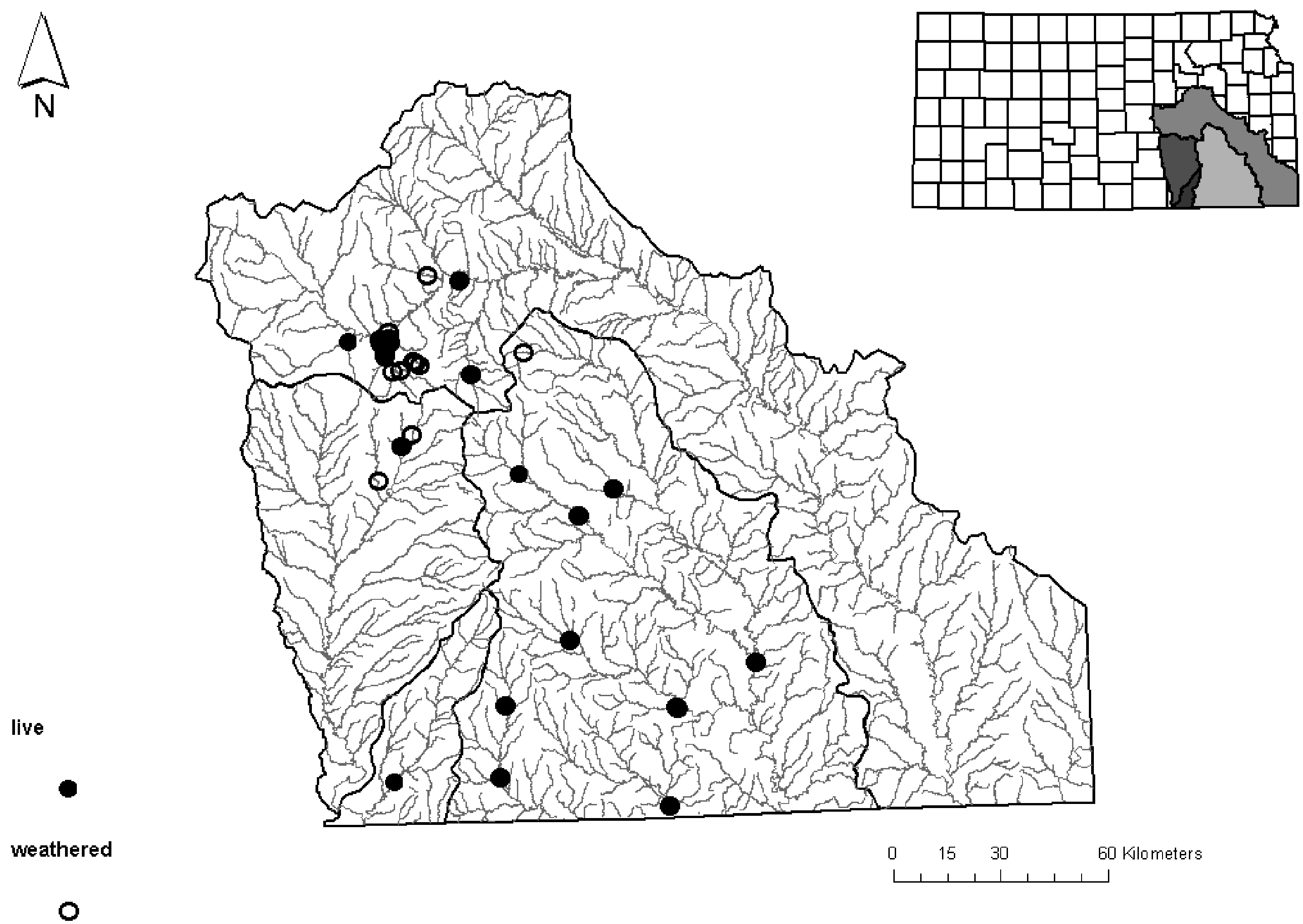


FIGURE 16. *Gyraulus parvus* collection sites in the Arkansas-Keystone, Neosho, Verdigris, and Walnut river basins.

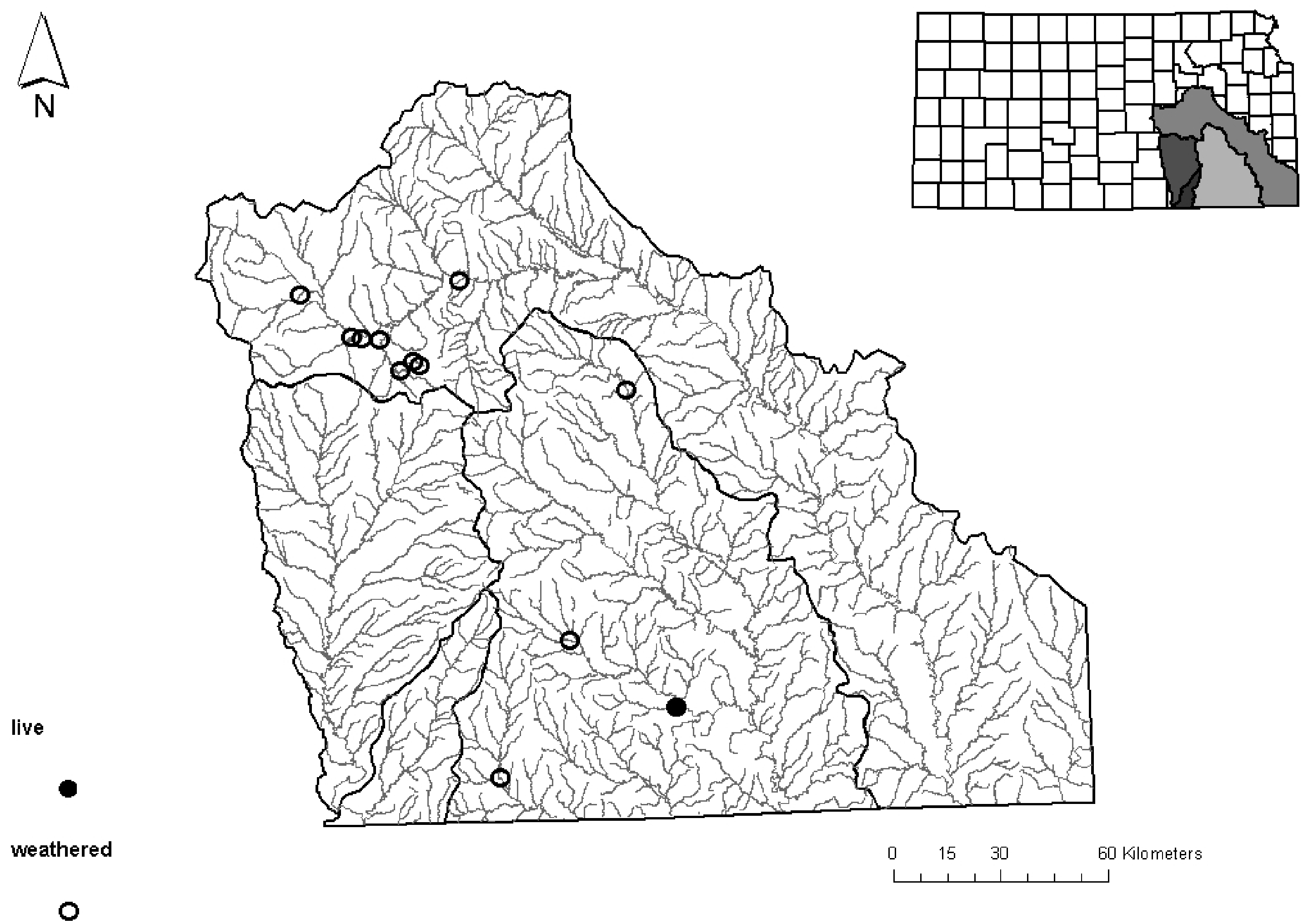
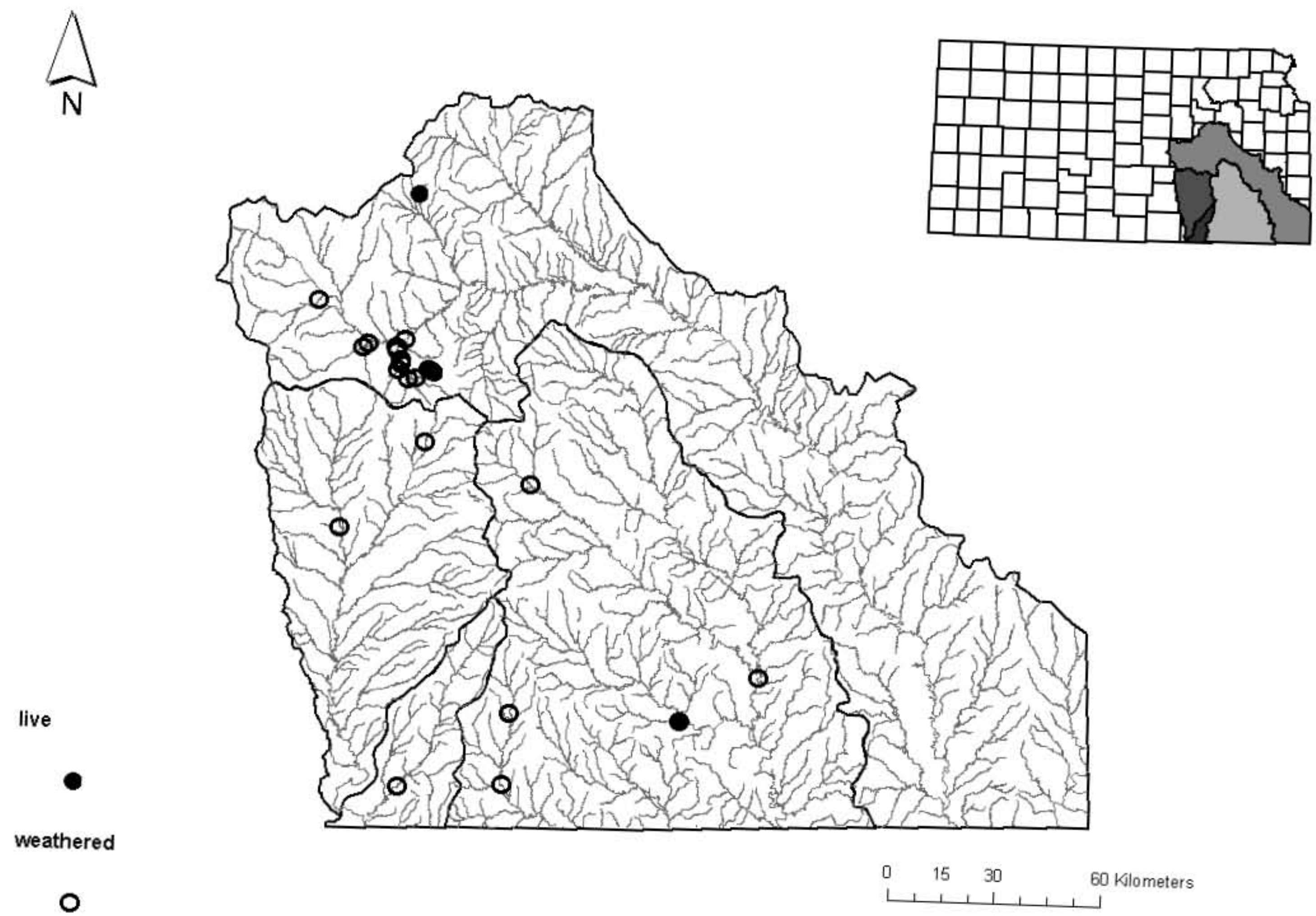


FIGURE 17. *Helisoma trivolvis* collection sites in the Arkansas-Keystone, Neosho, Verdigris, and Walnut river basins.



58