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TECHNICAL NOTE

Protocol for Large-Scale Monitoring of Riparian Mammals

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Keywords

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Abstract

The design of large-scale wildlife monitoring programs must include long term and geographically broad methods of collecting reliable information on the status and trends in populations, with the overarching goal of providing inference about ecosystem health. We developed a large-scale monitoring protocol for populations of beaver (*Castor canadensis*), American mink (*Neovison vison*), muskrat (*Ondatra zibethicus*), and North American river otter (*Lontra canadensis*) in Illinois, USA. The goals of the monitoring program are to (1) determine the distribution, status and trends of riparian mammal species in Illinois; (2) provide early warning of population declines; (3) contribute to baseline information and improve understanding of ecosystem dynamics; (4) produce data to meet certain legal mandates related to natural resource protection; and (5) measure progress towards wildlife management goals. We developed the riparian mammal protocol in an occupancy modeling framework and provide estimates regarding 2 levels of precision. The estimated number of sites required to meet benchmark precision values was consistently 4 times greater for management objectives requiring more certainty. As estimated occupancy and detection probability increased, estimates of the number of sites necessary to achieve the desired precision decreased. Based on our analysis, goals, and logistical constraints of the Illinois Department of Natural Resources, we recommend surveying 193 bridge sites with 4 survey samples annually for riparian mammals. The scientifically sound information obtained through this monitoring program will have multiple applications for wildlife management and understanding of riparian ecosystem dynamics.

Introduction

Monitoring biological diversity is important to identify populations in need of conservation action, assess the trend of one or more species, and to check the effectiveness of restoration actions [1, 2]. The most effective wildlife monitoring programs gather scientifically sound information on the status and long-term trends in populations, and determine how well management practices sustain those populations. The scientific value of monitoring comes via its temporal and spatial breadth; monitoring population trends is typically designed to be long term and geographically broad [3].

There is considerable overlap in many wildlife research and monitoring objectives, with the most important differences being that of scale. Short-term and small-scale research may assess many factors affecting wildlife populations; however, large monitoring databases offer opportunities for experimental ecology and ecological modeling relevant over large spatial and temporal scales, which can rarely be achieved by small-scale research programs [3]. Often there is little difference between the goals of research and monitoring; therefore, the most productive applications of science in ecosystem initiatives are those in which these pursuits are well integrated. The benefits come from the experimental and analytical opportunities that long-term, geographically expansive monitoring data tend to provide and the ability to test predictive models based on various population stressors [3, 4].

The Illinois Department of Natural Resources' (IDNR) mission is to "manage, conserve and protect Illinois' natural, recreational and cultural resources" thus knowing the population status of wildlife in Illinois is fundamental to that mission [5]. Increasingly wildlife managers are confronted with complex and challenging issues that require a broad-based understanding of the status and trends of wildlife populations as a basis for making decisions and working with other agencies and the public for the long-term protection of ecosystems. Developing a statewide wildlife monitoring program requires a front-end investment in planning and design to ensure that monitoring will meet the information needs of wildlife managers while producing scientifically credible data that are accessible to managers and researchers in a timely manner. The investment in planning and design also ensures that monitoring will build upon existing information and understanding of population status of focal species [6, 7].

The IDNR would benefit from the development of a monitoring protocol for populations of riparian mammals such as beaver (*Castor canadensis*), American mink (*Neovison vison*), muskrat (*Ondatra zibethicus*), and North American river otter (*Lontra canadensis*). As a group, these species play a disproportionate role in ecosystems by creating habitat, structuring the environment, and may function as keystone species [8-13]. Ultimately, this species group may serve as indicators of environmental health, but may also conflict with human interests [14, 15]. Beavers may damage resources (e.g. crops, roads, timber) used by humans, muskrat foraging may damage wetland vegetation at water treatment facilities, and the river otter diet of primarily fish may create conflicts with fish farmers [16-19].

In Illinois the muskrat and river otter are listed as "Species in Greatest Need of Conservation", and mink and beaver as Emphasis Game Species [20]. The

IDNR monitors the mammal Species in Greatest Need of Conservation largely opportunistically, and a paucity of information exists for the distribution and abundance of several species [20]. However, beavers have recently been studied extensively in central and southern Illinois [21-23]. Currently, IDNR obtains information regarding status of these species at large scales primarily through fur trapper questionnaires, recovered carcasses, and population modeling [20, 24, 25]. Samples obtained desultorily or by convenience can be flawed and mislead managers [26], thus data collected for monitoring programs must be adequate to generate reliable, precise, and defensible estimates of trends in wildlife populations upon which management decisions can be confidently based [27]. Therefore, the IDNR recently discontinued surveys of aquatic furbearer sign in Illinois [24], necessitating the development of a new survey protocol (R. Bluett, IDNR, personal communication). The primary goal of the sign survey program was to monitor progress of recovery actions (i.e. expanding distribution) for river otters. Surveys no longer provided useful information because river otters occurred throughout the state; therefore, IDNR rendered the approach obsolete given small sample size and recent quantitative innovations (e.g. occupancy modeling). The Illinois Wildlife Action Plan calls for landscape-level improvements to riparian habitat and surveys of semi-aquatic mammals might provide a means of assessing population responses to those improvements [20, 28, 29]. IDNR is therefore in need of a monitoring program based on reliable population data for riparian mammals throughout Illinois, which we developed as partners in conservation [20].

Complete population census data, although desirable for wildlife monitoring and habitat association, is virtually impossible to collect over long periods, especially at landscape scales [30, 31]. Low detectability is likely for solitary carnivores such as river otter and mink, which often occur at low densities [32, 33]. Given the development of new techniques to analyze detection-nondetection data, a practical alternative to monitor and assess habitat associations of riparian mammals in Illinois is to use surveys conducted throughout the state in an occupancy modeling framework [31, 34]. Further, site occupancy and ability to detect an aquatic mammal species' presence can change dramatically depending on rainfall levels, and thus water levels in riparian areas [35]. Therefore, monitoring programs need to account for potential differences in spatial and temporal detectability [1, 31, 34].

Much information is available for managers to develop monitoring programs; however, few published protocols developed within an occupancy-based framework exist for riparian mammals at large spatial scales. Here we describe the goals, required effort, and implementation strategy for long-term, statewide monitoring of riparian mammals in Illinois, USA (145,942 Km^2).

Program goals

1. Determine the distribution, status and trends of riparian mammal species in Illinois to improve IDNR wildlife managers' ability to make informed decisions and to work more effectively with other agencies.

2. Provide early warning of abnormal population declines and increases, as well as information required to develop mitigation measures, and reduce cost of management.

3. Gather baseline information for comparisons, and data to improve understanding of the dynamic nature and conditions of Illinois ecosystems.

4. Produce data to meet certain legal mandates identified by the U.S. congress related to natural resource protection through the Wildlife Conservation and Restoration Program, and State and Wildlife Grants Program legislation [20].

5. Provide a means of measuring progress towards wildlife management goals (e.g. Illinois' river otter recovery plan [36]).

Conceptual models

The process of designing conceptual models for a monitoring program improves understanding of system dynamics, anticipated stressors, and is necessary to select appropriate ecological indicators [6]. Based on our current understanding of riparian mammal ecology, we developed a simple conceptual model for factors that might affect populations (Fig. 1). Focal species will likely be directly affected by stressors such as legal harvest, poaching, human conflict, disease (e.g. tularemia, *Francisella tularensis*, for muskrat and beaver), accidents (e.g. vehicle-caused mortality, accidental harvest), and predation. Urbanization is expected to directly affect riparian mammals by reducing habitat and indirectly by affecting stressors, water quality and stream characteristics. Pollution, habitat fragmentation, channelization of streams, and wetland draining are a few of the aspects of urbanization that affect wetland mammals. Similarly, climate change will both directly and indirectly affect populations. We expect, due to climate change, the frequency of summer heat waves, waterborne disease, and periods of water deficits to increase in the Midwest [37]. Warmer temperature and higher precipitation (therefore flooding) may occur during winter [37]. Climate change may indirectly affect riparian mammals through changing riparian and stream characteristics, water quality, and interact with stressors. Changing temperature and precipitation regimes will likely influence species' distributions by directly affecting the physiology of individuals [38]. Increased water levels improve foraging conditions for riparian mammals, thus distribution of these species may increase spatially in wet years and be more restricted in dry years [35, 39, 40]. We expect riparian mammal populations will be affected by riparian characteristics, water quality, and stream characteristics, but the species may also alter those habitat features.

Interactions are likely for sympatric species sharing at least one niche dimension, and populations of one or all species may be influenced [41-43]. Therefore, we created a conceptual model to provide a working hypothesis of focal species interactions and relative strength of effects (Fig. 2). Beavers alter environmental conditions through construction of dams, lodges, and canals, which increases and improves resources for other riparian species [8, 18, 44]. Additionally, beavers, as well as mink and muskrat, may serve as prey for river otters [45]. Muskrat and mink share similar habitat in Illinois [46], and may interact tightly in a predator-prey relationship [42]. Mink and river otter may compete for resources, and because river otter is expected to be dominant, interactions will likely negatively affect mink populations [47]. These conceptual models should be refined and updated as biologists gain more knowledge about dynamics of the populations monitored.

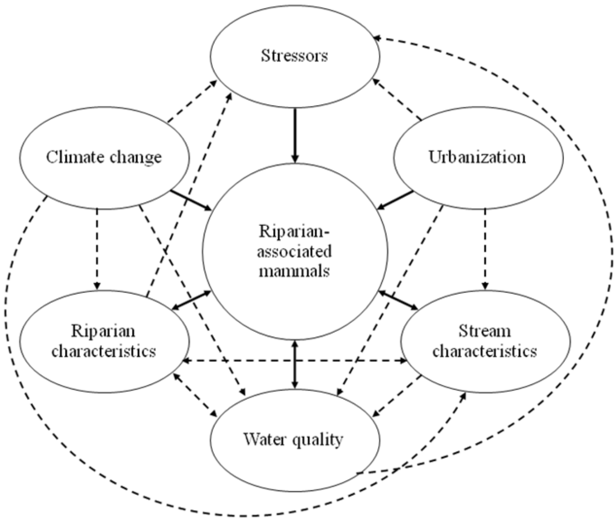

Fig. 1: Conceptual model summarizing factors expected to directly (solid lines) and indirectly (dashed lines) influence populations of riparian mammals in Illinois, USA. Populations will likely be directly affected by factors such as stressors (e.g. harvest, disease, predation), climate change, urbanization, water quality, and riparian and stream characteristics. Most factors (e.g. climate change, urbanization) will likely have both direct and indirect influence on populations by interacting with other factors. Riparian mammals are expected to alter their environment by affecting riparian and stream characteristics, and water quality.

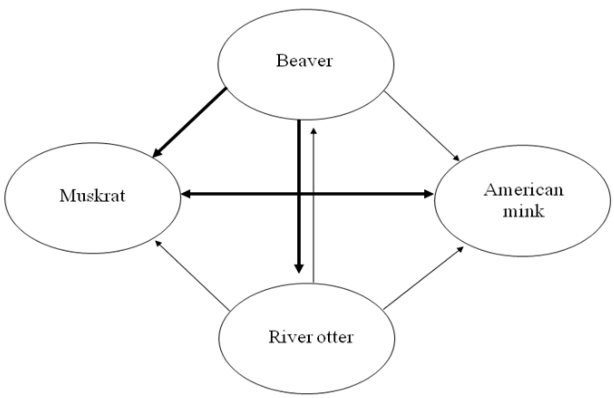

Fig. 2: Conceptual model of expected direction and strength of relationship between focal species as part of a monitoring program of riparian mammals in Illinois, USA. Arrow weights are perceived level of influence. Given engineering behavior, we expect that beavers will positively affect other species by increasing available habitat. Muskrat serve as food resource for American mink and river otter.

Sampling design

Given the need for monitoring programs to account for imperfect species detectability, and ability to predict species distribution [1, 31, 39], we designed this monitoring protocol within an occupancy modeling framework. The development of an efficient occupancy modeling protocol requires that the investigator define a period (i.e. season) in which species occupancy is closed (no immigration or emigration) and allocate effort between the number of sites to sample and the number of repeat surveys to perform at each site [31, 48, 49]. Single season designs provide a single occupancy estimate for a species, but if used for multiple seasons, investigators can detect changes in population distribution and detectability [31]. By conducting surveys for multiple years and modeling factors that may affect populations (Figure 1), dynamic properties colonization (γ) and extinction (ε) at local scales may be evaluated between years to determine why some sites are colonized and others are abandoned, thereby offering a more robust view of occupancy and turnover rates. For multi-season designs, seasonal changes in detection rate should be accounted for and the same sites should be surveyed the same number of times each season, which will provide investigators estimates of occupancy, colonization, and local extinction. Furthermore, large-scale monitoring with many sample sites provides information on turnover rates at multiple scales (site-level to statewide).

During a season, all sites could be surveyed the same number of times (i.e., standard design), or sites could be surveyed only until the presence of the species of interest is determined at the particular site (i.e. removal design) [31, 49]. Removal methods may require less overall effort than standard designs when detection probabilities are relatively high and constant; however, this design typically provides less flexibility for modeling [31]. The Illinois riparian mammal monitoring program will incorporate multiple species, thus requiring detections of all 4 species at a site to remove from further surveys, which may not be likely. Further, focal species detection probabilities are unknown throughout Illinois, will likely vary annually and seasonally, and may be low [33, 35]. Recognizing sampling design trade-off requirements, we used a standard sampling design because the monitoring protocol will include multiple species and benefit from having greater model flexibility [48].

We evaluated sample size requirements (i.e. number of survey sites) by calculating the necessary survey effort based on various estimates of occupancy (ψ), detection probability (p), and 2 different estimates of precision. For estimates of precision, a coefficient of variation (CV) of $\leqslant$ 0.26 is acceptable for studies that require only coarse management. However, for studies requiring more accurate management, a CV $\leqslant$ 0.13 should be used [50, 51]. MacKenzie *et al*. [26] suggested that CV be calculated as:

$$\mathrm{CV} = \frac{\sqrt{\mathrm{Var}(\hat{\psi})}}{\psi}$$

We used 4 repeat surveys at each site (K) to evaluate the number of sites and effort required to achieve the benchmark levels of precision because it is the optimum number for moderate ψ and p [31]. To evaluate the standard single-season design, we included the parameters described above into the standard equation:

$$\mathrm{s} = \frac{\psi}{\mathrm{Var}(\hat{\psi})}\left[(1-\psi) + \frac{(1-p^*)}{p^* - \mathrm{K}p(1-p)^{\mathrm{K}-1}}\right]$$

where p^* = 1 - (1 - p)K is the probability of detecting the species at least once during K surveys of an occupied site and $\hat{\psi}$ is estimated occupancy [31]. We incorporated assumed estimates of occupancy (0.10, 0.25, 0.45, 0.60), assumed detection probabilities (0.15, 0.25, 0.35), and K = 4 in Program GENPRES [52] to obtain estimates of the number of survey site requirements for benchmark precisions CV ⩽ 0.26 and 0.13 [48]. Preliminary data from mink and muskrat surveys conducted in central Illinois indicated occupancy rates and detection rates of 0.45–0.93 and 0.43–0.72, respectively [35, 40]. These rates are, on average, somewhat higher than those used in our calculations of sample size. We used a more conservative analysis because we expect intra-, interspecific, spatial and temporal variability in occupancy and detection rates for a statewide monitoring program.

Table 1: Number of sites required for 4 repeat surveys per season for riparian mammals in Illinois, USA, to achieve 2 levels of precision using coefficient of variance (CV) ≤ 0.26 and 0.13, with 4 levels of occupancy (ψ) and 3 levels of detection probability (*p*).

ψ	*p*	N° of sites (CV ≤ 0.26)	N° of sites (CV ≤ 0.13)
0.1	0.15	839	3355
0.1	0.25	312	1248
0.1	0.35	194	775
0.25	0.15	328	1310
0.25	0.25	116	465
0.25	0.35	69	275
0.45	0.15	175	700
0.45	0.25	58	232
0.45	0.35	32	127
0.6	0.15	128	510
0.6	0.25	40	159
0.6	0.35	20	80
		193[a]	780[a]

[a] Mean number of sites required to achieve a given CV ≤ 0.26 or ≤ 0.13.

The estimated number of sites required to meet benchmark precision values using a standard single season design was consistently 4 times greater for CV ⩽ 0.13 than CV ⩽ 0.26 (Table 1). As occupancy increased from 0.10 to 0.60, estimates of the number of survey sites necessary to achieve the desired occupancy precision decreased by 84.7 – 89.7%, depending on detection probability and CV (Table 1). As detection probability increased from 0.15 to 0.35, estimates of the sample size necessary to achieve the desired occupancy precision decreased by 76.9 – 84.4%, depending on occupancy and CV (Table 1). The mean minimal number of sites required to provide coarse estimates of occupancy is 193 sites visited 4 times, which will provide slightly more accurate estimates if ψ and *p* are greater than the values used in this analysis (Table 1). Further, monitoring 193 sites per season should provide adequate coverage of the state while balancing logistical constraints. The recommended sample size from this analysis appears to be the most appropriate goal for investigators monitoring riparian mammals in Illinois.

Monitoring protocol

Site Selection

Although all focal species of this protocol are associated with riparian areas, subtle habitat selection differences are likely [44, 53-55]; therefore, sites should be selected as to not bias interspecific detection. Additionally, sampling needs must be balanced

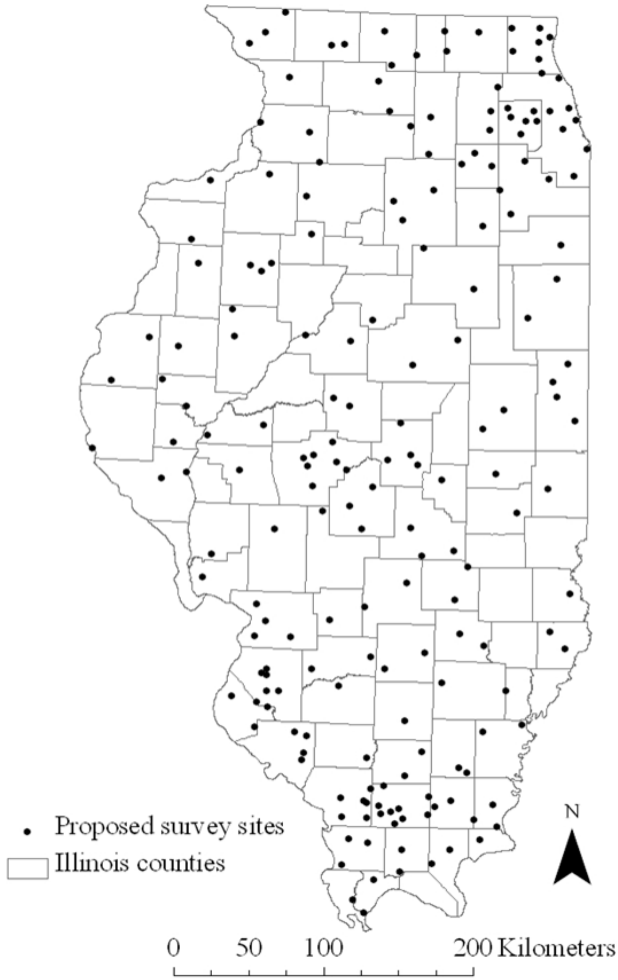

Fig. 3: Proposed survey sites (193) for riparian mammal monitoring in Illinois, USA. Sites were randomly selected from Illinois Environmental Protection Agency river and stream monitoring sites [55].

with logistical constraints, and purely random sampling designs often produce low detection rates for species [27]. Therefore, we randomly selected the 193 proposed survey sites throughout all Illinois Landscape Management Units (ILMUs) at Illinois Environmental Protection Agency (IEPA) river and stream monitoring sites [56], which are located at bridges over waterways of various stream classes and represent different habitat types in the state proportional to their occurrence (Figure 3). The IEPA maintains long-term publically-available data sets of water quality and stream flow at these monitoring sites.

Field Sampling

Monitoring programs should use reliable survey methods that are not reliant on rapidly changing technology, so to ensure consistent data collection over long periods [26]. Although researchers and Midwestern state conservation agencies have used many techniques to detect the presence of semi-aquatic mammals, bridge surveys appear to be the most appropriate to balance quality data collection and required effort [57]. The bridge survey was established and used to monitor otters in North America and Europe in the early 1980s by randomly selecting bridges and searching for signs of presence along waterways [58, 59]. Beaver, mink, muskrat, and river otter have home ranges that are often linear and correspond to riparian areas [60-64]. Sign surveys are appropriate for riparian mammals at large scales, and are less costly in labor and supplies than other methods [30, 65, 66]. Further, sign surveys provide reliable data that can be collected systematically at different geographic scales and linked to existing information about population status and site characteristics.

Distribution surveys often include imperfect detection during a single survey for evidence of a species' presence; therefore, multiple surveys during a season will be required to estimate detectability. To collect data required to develop occupancy models for each species and meet the goal of 4 survey samples per site for each year, a 2-person team trained to detect aquatic mammal tracks and sign will visit stream monitoring sites twice during August–October to meet the closed season (no immigration or emigration) assumption of occupancy modeling [31]. If properly trained and differences between observers are accounted for, volunteers may be utilized by IDNR to assist with data collection for the monitoring program [67]. The length of time between seasons will be one year. Because river otter detection probability increases with distance from bridges [68], team members will walk separately along both sides of the stream 400 m in different directions (1 upstream and 1 downstream; totaling 800 m of stream surveyed) from bridge access and search for and record sign of each species (Table 2, [69]). This technique will allow for 2 samples (1 per biologist) for each site visit and 4 survey samples per year.

Table 2: Riparian mammal signs to be recorded during bridge-sign surveys in Illinois, USA.

Species	Signs
Beaver	Burrows, channels, debarking, feeding signs, felled trees, lodges, runs, scat, scent mounds, tracks
Mink	Feeding signs, scat, snow tunnel, tracks
Muskrat	Burrows, channels, debarking, digs, feeding signs, lodges/dens, runs, scat, tracks
River otter	Bedding sites, diggings, feeding signs, latrines, runs, scat, tracks

Site and survey data are required to assess and make inferences about factors that could influence riparian mammal populations and ability of biologists to detect their presence. Therefore, biologists will record the following data for a site survey:

- survey date
- site number
- rank of suitable bank conditions
- species sign found
- type of sign
- distance from bridge to first sign

- temperature at time of survey
- mean temperature for previous 7 days
- time since last precipitation
- total rainfall during previous 7 days
- observer
- stream order
- number of human dwellings within 100 m (perpendicular) of surveyed section of stream
- miscellaneous notes about site

The suitable bank condition rank will be recorded on a scale of 0–10, with each point representing a 10% increase in conditions of bank suitable for showing sign. For example, the site would be given a low score if the bank substrate is completely stone, but a high score if the bank is mud suitable for leaving tracks by study species. Observer effects are common for sign surveys for aquatic mammals, especially those occurring at low densities [70, 71], thus observers will be controlled for as covariates in detectability models. Weather conditions can negatively affect detectability of riparian mammals [35], therefore surveys will not be conducted in conditions not favorable to finding signs of presence (e.g. within 2 days of a substantial rainfall event, or rising floodwaters). If a survey must be terminated due to inclement weather then the survey will be conducted the next suitable day.

The IDNR should gather information from various sources and include those data in models for riparian mammal populations to address the effects of factors presented in the conceptual models. At each site during each year, biologists should record **1)** the level of urbanization (number of human structures, and length of major and minor roads) within 2-km of sample site; **2)** measure of water quality and stream characteristics from IEPA data sets; and **3)** riparian characteristics (average width and type [e.g. woody, herbaceous] of riparian zone, distance to nearest agriculture field). Additionally, annual climate data (temperature, precipitation) and known population stressors (harvest, wildlife control measures, disease, and road kills) should be recorded and summarized for each ILMU and statewide.

Data analysis

Using an information-theoretic approach, biologists should develop models with several environmental factors that may affect riparian mammal populations by quantifying ψ, p, γ, and ε. To assess multi-scale habitat associations and impacts on species co-occurrence, IDNR biologists should develop models with variables collected on-site and those measured using a geographic information system (e.g. cover type proportions and structure at larger scales) prior to collecting data and refine those models as knowledge about the system is gained. Using data collected from surveys and those from the Illinois Environmental Protection Agency monitoring data set, encounter histories will be analyzed in Program PRESENCE 3.0 [72] and models ranked based on their AIC values and Akaike weights (w_i) to select the most supported model [31, 73].

Discussion

We have provided a statistically rigorous survey protocol for monitoring riparian mammals within an occupancy modeling framework. Although we use the state of Illinois as an example, the protocol can be modified to be applicable to many other ecosystems where the monitoring of riparian mammals is a goal. Of particular broad relevance are the conceptual models for factors that might affect riparian mammal populations, sampling design and field sampling methods. Having little empirical data available, we made assumptions regarding potential detectability and occupancy of focal species. Further, we acknowledge that given the need to simultaneously monitor multiple species, a single, optimal sampling strategy is likely not possible [27]. However, the level of sampling intensity should be based on the rarest or hardest to detect species because not doing so would produce data unusable for a monitoring program. As biologists gain more knowledge about dynamics of Illinois riparian mammals, we recommend they refine and update conceptual models and protocols developed to ensure usable data are collected. Models for each species should evolve in an adaptive way as new information regarding riparian ecosystems in Illinois becomes available. To move beyond the theoretical framework of this monitoring protocol and estimate parameters, which will effectively test the capability of the proposed plan, we recommend IDNR develop and fit models using the first year of field data and refine the protocol accordingly. Furthermore, based on information gathered, we recommend the protocol be refined and updated annually for a period of five years then biannually thereafter.

This protocol will contribute to gathering essential information for the IDNR to make informed management decisions and effectively work with other wildlife agencies. Baseline information on species' distribution and status provide an ability to determine population trends and the identification of abnormal increases and decreases in populations. Wildlife agencies are increasingly required to meet natural resource legal mandates, which are assisted with robust population data and factors affecting those populations. Finally, this monitoring protocol will provide the IDNR a means to assess management objectives and make inferences about riparian ecosystem dynamics throughout the state.

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Five "key references", selected by the authors, are marked below (*Three recommended* (●) *and two highly recommended* (●●) *papers*).

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