Collection of Scientific Specimens: Benefits for Biodiversity Sciences and Limited Impacts on Communities of Small Mammals

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Despite increasing use of specimens from natural-history collections, continued field sampling has met with growing resistance attributable to changing societal values. Widespread perception persists that the removal of individuals from wild populations will affect the integrity of natural communities. Ecological studies often document the resilience of wildlife to sustainable removal and the negligible contributions to mortality of scientific collecting compared with those of other natural or anthropogenic-induced causes. Nevertheless, few studies have directly assessed the consequences of specimen removal on populations or communities. We present long-term ecological research data that suggest removal trapping has negligible impacts on the species richness, diversity, or abundance of small mammals. The maintenance and future growth of natural-history archives for integrated biodiversity sciences may hinge on increased dedication to specimen vouchering across ecological and evolutionary disciplines and wider acceptance by regulatory authorities and funding agencies. The effects of low-intensity collecting should be investigated for other taxa and across biomes.

Keywords: community ecology, long-term research, museum voucher, natural-history collections, removal trapping

> "Why such zeal to prevent a few birds from being collected for science, while killing millions of birds without contributing to knowledge?"
>
> —Jared M. Diamond (1987)

Diamond (1987) argued that the responsible collection of biological specimens provides a necessary foundation for effective conservation and wildlife management policy and is integral to rigorous and interdisciplinary biodiversity sciences. Museum specimens archived in natural-history collections have experienced increased use in recent decades, particularly for characterizing evolutionary processes (Holmes et al. 2016), understanding the impacts of environmental change on ecosystem structure and function (Rocha et al. 2014), and exploring the ecology of emerging diseases (Yates et al. 2002). The inherent value of preserving representative vouchers from wild populations has received recent attention. Examples include benefits for biodiversity conservation (Patterson 2002), human or wildlife health (DiEuliis et al. 2016), and implementing new technology (Bi et al. 2013) but also for economic (Suarez and Tsutsui 2004), environmental (Dunnum and Cook 2012), and ethical and philosophical consideration (Winker et al. 2010, Clemann et al. 2014). Despite the increased value and greater use of research archives for science and education, the practice of collecting biological specimens continues to decline, along with support for the maintenance and growth of the institutions that store natural-history resources in perpetuity (Winker 1996, Prather et al. 2004, Kemp 2015). These declines have not been universal, and a small number of collections have maintained or increased numbers of accessions through time by investing significant effort to support a minimal staff and at least temporarily overcome funding limitations (Winker 2004, McLean et al. 2016). However, negative perceptions of specimen collection continue among some policymakers, regulatory authorities, and the public—including funding agencies that have traditionally supported museum growth—suggesting that the removal of biological specimens from natural populations will detrimentally affect community structures, population densities, or the viability of rare species. Restrictions on scientific collecting, in turn, jeopardize the availability of robust natural-history resources to enable future understanding of complex dynamics (Patterson 2002).

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Two key objectives of biodiversity and natural-history sciences, whether from ecological or evolutionary perspectives, are (1) to understand and maintain functional ecosystems and (2) to understand how organisms respond to changing environments through time (Cardinale et al. 2012). Specimen-based sciences generally support comparative methods across great spatial and temporal scope that are relevant to broadscale policy decisions (Winker 1996). Comparative approaches based on observation and the study of specimens are often the only options for testing questions that are central to macroevolution, systematics, and other disciplines within evolutionary ecology. However, observational methods based on natural history have been viewed with skepticism by some scientists with a notion of higher rigor or scientific value through the experimental method of manipulating variables in the field or lab to answer questions through the testing of proposed hypotheses. A relevant question to the topic of specimen collection would be "does removing specimens from natural systems significantly and negatively affect wild populations, or community structure and function, compared with nonremoval methods?" Skeptics of the value of vouchering biological materials in museums often assume that the negative impacts of collecting and archiving whole specimens outweigh those of nonlethal sampling, such as observational data, or those of noninvasive sampling of blood, feces, hair, or other tissues. Similarly, specimen-based research often does not operate within a discrete experimental system that permits the quantification of the impacts of collecting.

The long-term benefits of maintaining voucher specimens in natural-history collections, as well as contrasting viewpoints for the practice of specimen collection, have been reviewed in depth (Remsen 1995, Winker 1996, Collar 2000, Winker et al. 2010, Clemann et al. 2014, Minteer et al. 2014, Rocha et al. 2014, Webster 2017). Although qualitative data argue for the inherent value and benefits of collecting, few controlled experiments have evaluated the impacts of scientific collecting on wildlife populations. We present an assessment directly testing whether removal trapping to generate voucher specimens can have a negative impact on species richness, diversity, or abundance within natural communities compared with nonremoval methods.

Our goals were twofold: (1) to perform a rigorous test of the impacts of specimen removal on the long-term dynamics of a vertebrate community and (2) to consider how interdisciplinary science can be enhanced through the collection of voucher specimens by providing more comprehensive biodiversity data regarding the integrated association of hosts, parasites, and pathogens in addition to relevant ecological field data. Ultimately, the integration of all vouchered specimen parts constitutes a core value of natural-history collections by allowing for repeatability and falsifiability under the scientific method. Together, these goals (a) provide perspective as to what factors may significantly affect natural communities and (b) emphasize the joint potential that the life sciences and management have for building and using mutual resources. A synthetic framework may help to ensure the long-term stability and growth of natural-history collections through the recognition of specimen-based research institutions as a legacy, resource, and responsibility of all biodiversity sciences and associated regulatory authorities and conservation groups (McLean et al. 2016).

The study site and its history of data acquisition

Long-term research initiatives provide a key area where we might enhance the integration of specimen-based investigations within experimental systems (Cook et al. 2016). Long-term experiments offer great potential for providing site-intensive temporal series of specimens to document and understand historical biotic responses to change and predict possible biodiversity scenarios in the Anthropocene era (Hoberg et al. 2003, Cook et al. 2005). The Sevilleta Long-Term Ecological Research (LTER) site in central New Mexico, United States, has been collecting community data on the regional small-mammal fauna at multiple sites since 1989. Small-mammal data based on long-term mark–recapture methods have involved live-trapping on grids where all specimens are released in order to study long-term population dynamics and community structure. In addition, a multiyear study of associated parasite biodiversity was conducted on replicated removal sites, where specimens were captured on grids but were collected using lethal sampling. For the subset of sites used for parasite sampling, host specimens of small mammal were removed, prepared as study voucher specimens, and archived along with their parasites within natural-history collections. Until now, a statistical analysis of the effects of removal trapping on the small-mammal fauna has not been conducted, but such analysis was not an original goal of these two projects. However, because the field sampling of mammal communities was based on a comparable trapping approach, the joint data sets provide a rare opportunity to test the ecological impacts of long-term removal trapping on natural communities of small mammals.

The Sevilleta (SEV) LTER program is located within the Sevilleta National Wildlife Refuge in central New Mexico, United States. The SEV LTER site was designed to study ecological processes in an arid-land ecosystem. The study site is located at a complex set of ecotone transitions between desert grassland, shrubland, woodland, conifer forest, and riparian habitats. These habitats represent five regional biomes that extend through much of the central and western United States and northern Mexico. Consequently, the SEV supports a high diversity of small nonvolant mammals (approximately 30 species) that form diverse and habitat-specific community associations.

Small-mammal community, population, and individual specimen data were collected across six separate study sites that were representative of the different habitats. The LTER data set includes both the small-mammal mark–recapture data (Newsome 1989) and rodent-parasite data (small-mammal removal; Duszynski 1990). Two study sites were located in grasslands (Five Points Grassland, Rio Salado

Grassland), two in shrubland habitats (Five Points Creosote, Rio Salado Creosote), and two in woodland (Juniper Savanna and Piñon-Juniper Woodland). Trapping and data-collection methods have been described in detail by Wilson and colleagues (1997). Briefly, each of the six study sites contained five standard trapping webs, with two randomly chosen for removal trapping (hereafter "removal"), and three for live mark–recapture (hereafter "release"). Each circular web was 3 hectares in area, containing 148 Sherman live traps set in 12 radial transects of 12 traps, with an additional 4 traps at the center. Treatments were consistently applied to each trapping web for the duration of the study. All sites were trapped for 3 consecutive nights in spring and summer for the 3-year period of 1991–1993 and during spring and fall for the 5-year period of 1994–1998. For release treatments, all captures were identified to species on the basis of standard measurements and external characteristics and were tagged before being released at point of capture, and recaptured individuals were recorded within trapping periods. For removal treatments, all specimens collected for necropsy were euthanized following approved methods for animal welfare under Institutional Animal Care and Use Committee protocols (Sikes et al. 2016 and previous editions) and under valid state and federal permits for wildlife research, including scientific-collection permits and authorizations to work on refuge lands. All small-mammal specimens, including frozen tissues, and ecto- and endoparasites were archived in the Museum of Southwestern Biology. All associated parts and specimen data are accessible through the international Arctos database for specimens in natural-history museums (*http://arctos.database.museum*).

Community- and species-level analyses

No data for recaptured individuals were recorded for 1991, and this year of data was not included in our analyses. From the remaining 7 years of data, 11 individuals were not identified to species and were also censored from analyses. The sampling totals for the removal and release treatments were averaged over two or three webs, respectively.

Both the community-level and species-level analyses were performed in R (R Development Core Team 2014) using the packages lme4 (Bates et al. 2015) and vegan (Dixon 2003). The count data were initially explored for relative fit to Gaussian or Poisson distributions. Most of the individual species counts best fit a Gaussian distribution, which was used in all subsequent models. Within each site, we statistically assessed community metrics of average species richness and Shannon-Weiner species diversity, as well as abundance counts for the two numerically dominant species, by applying an analysis of variance (ANOVA) considering factorial models. Our analyses considered all seasons and years as independent sampling periods (two seasons per year for 7 consecutive years). Our factorial models incorporated the random effects of different sampling webs per site, as well as the fixed effects of the sampling period, the trapping treatment (removal versus release), and the interaction between these two factors.

The impact of removal trapping on mammal communities

Long-term field sampling from the SEV LTER yielded data for over 13,000 individuals, averaging over 300 individuals captured per site per year (supplemental table S1). Species richness, diversity, and abundance varied significantly among years (supplemental tables S2 and S3), likely responding to interannual climate and resource fluctuations (Brown and Heske 1990). However, we found few significant interaction effects between sampling period and treatment. Therefore, despite considerable temporal variation in the population numbers of small mammals, the differences between removal and release treatments were limited and nonsignificant for either richness or diversity (figure 1, table S2). In addition, recurrent removals had no measurable impacts on the numerical abundance of the most common species (figure 2, table S3). Considering 12 tests for the most numerically dominant taxa (top two species per habitat), in only one instance was abundance significantly influenced by removal treatment, but in the case of *Peromyscus boylii* (figure 2, table S3), there was also a significant interaction effect among treatment and period. Although beyond the scope of this study, variations among individual species responses hint at the complexity of community dynamics and inherent variability, even within species (e.g., *Dipodomys merriami*) and among years (figure 2, table S3).

If removal trapping has a persistent detrimental impact on individual species dynamics, then we might expect an initial decline at the onset of treatment, an annual effect with seasonal rebound, a steady decline in total numbers caught through time, or some combination of these three scenarios. None of these patterns were detected. Instead, the total numbers of individuals sampled through the duration of data collection matched the sampling effort by treatment (38% of the total were removal individuals from 40% of the total traps set; 62% of the total were released individuals from 60% of the total traps; table S1). The abundance of small mammals at the removal and release sites covaried in parallel, suggesting that the removed animals were quickly replaced by immigration or local recruitment. Last, the highest abundance observed across all the sampling periods was detected during the final 2 years of this 7-year data set, following multiple years of removal trapping (table S1).

Why multiple sampling methods matter for biodiversity sciences

Investigating the direct effects of field sampling. A proactive understanding of the potential benefits of specimen removal should consider insights for future quantification of *how* species respond to community reorganization through disturbance (in this case, specimen removal). For instance, why do we see only minimal effects on small-mammal community structure, and what are the mechanisms that drive such resilience within wild systems? Changes in abundance of the most common species often reflect trends in total

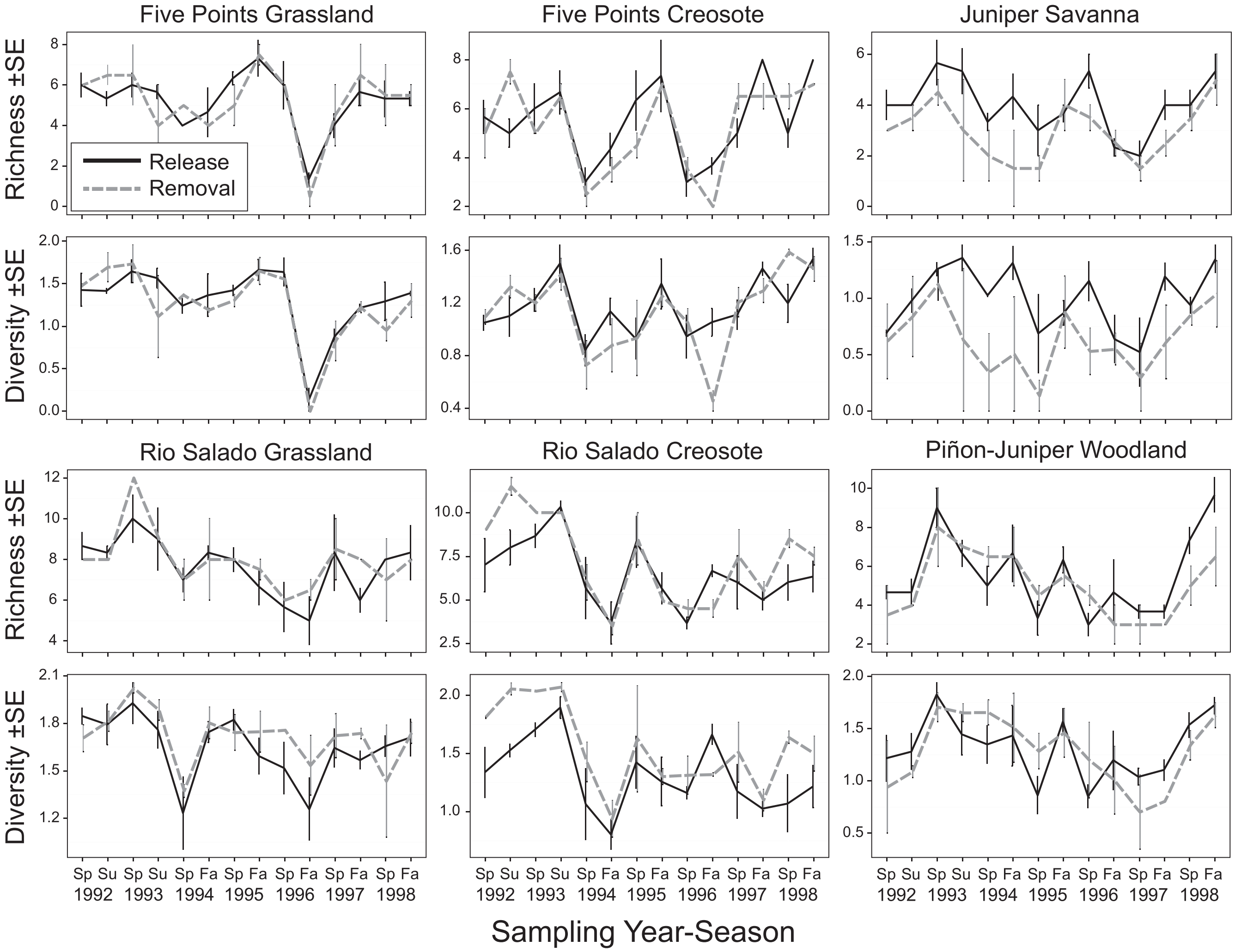

Figure 1. Variation in species richness and species diversity (Shannon-Weiner index) of small mammals from six discrete sites across the Sevilleta LTER between 1992 and 1998. The values for each site constitute averages across two or three trapping webs for removal or release treatments, respectively (148 traps per web for 3 nights per sampling period). The bars indicate standard error.

community abundance within a given habitat, and in addition, common taxa may directly influence higher-order community dynamics. By extension, major community changes may vary by site depending on the particular life-history characteristics of those dominant species, even though environmental variability is shared among sites. Our results indicate that population and community responses among rodent species can be rapid and highly variable. It is therefore critical to understand what factors drive such changes in species abundance. For example, there is a repeated occurrence of population declines among dominant species across sites during 1996 to consistently low levels, and this is reflected by parallel trends in community metrics (figures 1 and 2). Declines were followed by dramatic rebounds during 1997–1998. Major fluctuations in abundance were not affected by removal sampling. Instead, population declines in the small-mammal community occurred synchronously throughout the southwestern United States and coincided with a La Niña drought event, whereas subsequent population explosions followed one of the wettest El Niño events on record (Yates et al. 2002). The fortuitous timing of this field manipulation clearly demonstrates that scientific specimen collection had no discernable influence on climate-driven community dynamics within the semiarid zone of the SEV LTER. However, significant climate effects across seasons and years also suggest that human mediation of environmental and climate changes into the future *will* significantly affect wildlife.

Our study provides a single example within a discrete time frame, focusing only on nonthreatened mammals from a single ecosystem, and with a relatively dispersed and nonintensive trapping regime. Nevertheless, our data set extended across 7 years at six discrete sites, providing rigorous replication of the observed results. To address issues

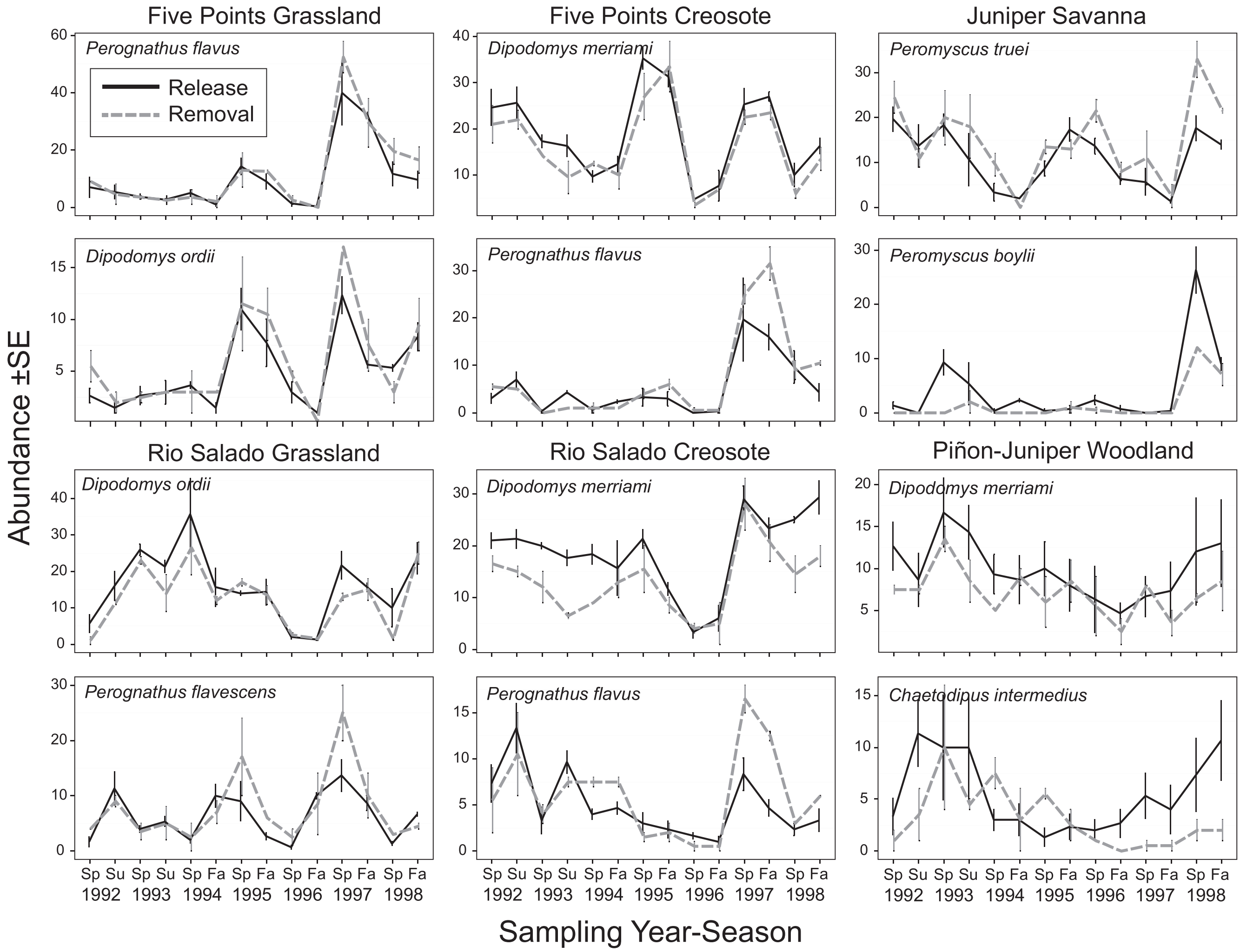

Figure 2. The variation in abundance (counts of individuals) of the top two numerically dominant small-mammal species for each of six sites sampled across the Sevilleta LTER between 1992 and 1998. The values for each site constitute averages across two or three trapping webs for removal or release treatments, respectively (148 traps per web for 3 nights per sampling period). The bars indicate standard error.

related to the relative impacts of specimen collection in the context of ecological studies, it will be crucial to develop and implement additional long-term experimental sampling efforts (Cook et al. 2016). Comparison of different jurisdictions shows wide variation in the specimen allowances set by different permit agencies within the United States and across Canada (Winker et al. 2010). It would be helpful to investigate whether the community responses to removal reported here would apply across biologically meaningful boundaries, such as across different biomes, among different intraspecific lineages, or within different taxonomic groups. Quantitative studies of the effects of specimen removal are rare but encompass rodents (Sullivan TP et al. 2003, Sullivan TP and Sullivan DS 2013), shrews (Nicolas et al. 2003), lizards (Poe and Armijo 2014), and arthropods (Gezon et al. 2015). Past studies have consistently found no permanent detrimental impacts of specimen removal on the respective wildlife communities. Taken together, the results of past studies and our analyses of the SEV data suggest that population impacts are negligible for short-lived species under the relatively light sampling protocols associated with museum collecting. Furthermore, although we did not consider life-history differences among taxa such as territoriality, life span, and fecundity within or among taxonomic groups (Sandercock et al. 2011), our analyses of individual species highlighted relative abundance within these diverse mammal communities, with each site supporting both common and more rarely encountered taxa (table S1). Future meta-analyses of additional experimental studies would aid in our understanding of the relative effects of removal methods across multiple ecosystems and taxonomic groups.

Developing a holistic understanding of biodiversity. A major concern regarding the implementation of removal sampling and voucher collection is the potential risk of affecting the viability of comparatively rare species (Minteer et al. 2014), often reflecting a lack of data (Böhm et al. 2013). Instead, it is crucial that adequate sampling be performed to detect and voucher rare taxa for investigating their specific ecologies and evolutionary histories and to provide a more holistic understanding of biodiversity (Winker et al. 2010, Rocha et al. 2014, Webster 2017). Our results provide additional insight regarding these "rare" taxa. First, rare species were seldom encountered, suggesting that significant trapping effort is often required to detect all species present in a target area (Winker et al. 2010). We did detect uncommon taxa within both release and removal treatment areas, indicating that these species are inherently rare but integral components of the community. Of particular interest, rare species were caught in proportionally higher abundance from removal treatments, suggesting that the detection of rare taxa may be masked by the presence of more common taxa (Patterson et al. 1989). In addition, having physical and proportional voucher representation of both common and rare taxa provides a useful context for other lines of investigation—such as parasite prevalence coupled with host specificity (Wilson et al. 1997)—that cannot otherwise be gained.

Community studies that solely use mark–release instead of a variety of sampling methods will likely fail to accurately assess species richness or diversity (Patterson et al. 1989, Voss and Emmons 1996). Implementation of an element of removal methods provides improved accuracy within an ecological monitoring context. Within our study system, richness did not significantly change as a consequence of removal trapping through the duration of sampling, indicating that no rare species were lost from the system. Furthermore, combined treatments of release and removal trapping can minimize "data deficiency" as a factor driving regulation of field investigations, particularly studies that incorporate specimen collection of inherently rare species (Winker et al. 2010). Ultimately, holistic sampling of hosts, parasites, and associated natural-history information can more accurately be extended to generalizable models of biodiversity responses across temporal and spatial scales (Hoberg et al. 2003, Winker 2004).

Increasing rigor among disciplines. All biodiversity scientists can practice responsible accessioning of salvaged specimens, experimental mortalities, and voucher specimen representation and should be challenged to do so by regulators, funders, peer reviewers, and nongovernment organizations (Winker et al. 2010, Turney et al. 2015). As we have demonstrated, specimen vouchering offers increased rigor for the investigation of complex density-dependent processes, and the ecological interactions can then be related to continuing environmental perturbation and evolutionary or coevolutionary dynamics through incorporating knowledge of associated biodiversity (e.g., parasites, pathogens, and diet). The incorporation of multiple sampling methods into long-term experimental systems should have added benefit for the scientific disciplines that generally do not combine these criteria. For instance, the majority of specimen removal up to the present has been opportunistic to maximize geographic coverage and has been associated with disciplines in which access to curated materials is essential, generally for evolutionary investigations (Winker 1996) but including multiple other analyses (e.g., stable isotopes). One common shortfall of field collections is the uncertainty surrounding species occurrence or population densities per sampling time or locality, given the stochastic nature of community assembly (Remsen 1995). On the other hand, long-term ecological studies often have well-documented background information on the population and community characteristics for a given area, making work with sensitive species more tractable (Henttonen et al. 1987, Brown and Heske 1990, Meserve et al. 1999). Experimental systems with more site-intensive sampling provide increasingly accurate expectations of relative diversity through time compared with more infrequent sampling of wildlife communities, such as only once or every few years.

At times, both evolutionary (Peterson et al. 2007) and ecological research (Bortolus 2008, Turney et al. 2015) has been criticized for failing to voucher study animals, not citing the disposition of specimens collected for research (McLean et al. 2016), or discarding specimens collected during survey work instead of accessioning representative materials in long-term natural-history collections (Sullivan TP and Sullivan DS 2013, Cook et al. 2016). Many ecological studies do not yet incorporate protocols for specimen vouchering, but the long-term data sets presented here provide valuable support for biological collections by revealing that wildlife can be resilient to severe population fluctuations, coupled with specimen removal (Henttonen et al. 1987). Behavioral and environmental impact studies have quantified mortality associated with natural and anthropogenic-induced causes, although often without accompanying preservation of casualties (Winker 1996). Wildlife and land managers carefully monitor the annual harvest of game species, often without representative vouchers to trace changes in demography or genetic diversity through time (Winker et al. 1991). Conversely, digitized natural-history collections report numbers of new specimen accessions annually (Suarez and Tsutsui 2004, McLean et al. 2016). Specimens curated for science and education account for a small fraction of total mortality compared with that from other direct anthropogenic causes. For example, building strikes, hunting, roadkill, and domestic cats, to name a few, each account for millions of vertebrate mortalities annually, each more than natural-history collections have accumulated in centuries (Arnold and Zink 2011). Scientific specimens are therefore disproportionately beneficial for understanding and reducing threats to natural population densities, including human-exacerbated environmental perturbations (Remsen 1995, Patterson 2002).

A major hurdle for implementing a component of specimen vouchering within experimental systems is the additional effort and expense associated with these collections. The financial burden of specimen curation includes the field costs of collection; maintaining an adequate museum staff and facilities, including training future generations of curatorial specialists; and specimen preparation and storage (Dunnum and Cook 2012). Although it is impossible to put a monetary value on archived specimens, it is possible to put a price estimate on the long-term preservation of a given specimen. Attempts to do so have factored in many associated costs (Bradley et al. 2014). More difficult is anticipating the financial need associated with a project given the uncertainty surrounding specimen densities encountered during field sampling. However, long-term research initiatives again have an advantage. Knowledge of population cycles and local diversity and density dynamics through time will facilitate more rigorous budgeting for interannual variation in specimen acquisition. As field collections continue to increase, anticipation of accurate numbers (and monetary need) may be refined, particularly in conjunction with digitized specimen databases that document annual influx by institution. Ultimately, future expenses will require additional support from funding entities, both directly to natural-history collections and also by encouraging independent research initiatives (such as long-term ventures), to budget for specimen preservation. Additional innovative ways to overcome financial obstacles will increasingly include the development of educational outreach and opportunity through a volunteer and student workforce, successful multi-institutional digital or online teaching initiatives, and integration across scientific disciplines, increasing productivity through resulting collaborations and publications (Cook et al. 2014).

Conclusions

The small-mammal and parasite data sets from the SEV LTER program demonstrate how scientific potential has been realized as a consequence of multidisciplinary data collection. The original projects independently incorporated community ecology, parasite systematics and evolutionary ecology, and a natural-history commitment to preserving biological materials. All specimens from the removal treatments (supplemental table S4) were archived alongside their associated parasite biodiversity and effectively document the taxonomy and complexity of species associations existing within long-term experimental systems. Our results raise a series of interesting questions concerning community assembly and ecological species interactions under scenarios of perturbation. This experimental system highlights the integration that specimen-based science affords and the potential for collaboration through shared resources (McLean et al. 2016). As such, data from a given project have potential to increase in value if associated with other investigations that use the same specimens. We have shown that responsible specimen removal can have little impact on wild small-mammal communities. The sampling considered in this study is consistent with most specimen-based investigations, in which periodic 3–5 nights of sampling at a given site can result in efficient specimen recovery for the time and resources spent. Concerns for experimental integrity within ecological studies that mandate a hands-off approach can still benefit from at least limited representative specimen vouchering from parallel or proximate sites or else at different times from experimental data collection within the same site. Developing an understanding of the value of scientific specimen collection is not limited to managers and agencies whose primary responsibility is to the wildlife or to long-term experimental systems. Areas where habitat destruction for industry and development are most severe often constitute regions experiencing critical wildlife declines without any specimen acquisition to document loss of biodiversity or the investigation of the processes of change (Diamond 1987, Böhm et al. 2013). Large-scale habitat conversion is generally also accompanied by some of the highest resistance to specimen-based discovery (Ribeiro and Freitas 2014). Results from our study, based on long-term data, should serve to inform and motivate regulatory authorities to develop quotas for specimen collection that are based on scientific guidelines and that allow for detection and museum preservation of both rare and common taxa with temporal and spatial breadth. Revitalizing the future of research archives by supporting and enabling rigorous field studies that incorporate responsible specimen collection is ultimately proving to benefit both wildlife communities and human society within a rapidly changing world (Suarez and Tsutsui 2004).

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Supplemental material

Supplementary data are available at *BIOSCI* online.

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