Natural Science Research Laboratory

50TH ANNIVERSARY REPORT

CONTENTS

Funding for this report provided by
Dr. Aaron Pan, Executive Director of the Museum.
Content compiled by Lisa C. Bradley.
Design and layout by Mystie Do.

Natural Science Research Laboratory 1973–2023

Fifty Years of Excellence in Research, Graduate and Undergraduate Education, Scholarship, Collections Care, Curation, and Growth, and Public Engagement

Report prepared by the Director and Staff of the NSRL

Acknowledgments

The curators and staff of the NSRL that prepared this report wish to sincerely thank and recognize the many colleagues, students, collaborators, and administrators over the years who have supported the mission of the NSRL in research, education, engagement, and collections preservation. As evidenced by the testimonials of former students, former staff, research associates, and colleagues at other natural history museums (see Appendix C: *Testimonials*), the natural history collections community is a supportive group with a common mission. This mutual respect for the value of natural history collections allows for collaborations that result in scientific discoveries, scholarly output, newly trained professionals in science, academia, and museum science, and advancements in curatorial standards and collections care. Although the NSRL's 50th anniversary motivated the production of this report, and, yes, it is a way to "brag" about the NSRL's accomplishments, this report is not meant in any way to negate or lessen the value of other natural history collections and the vital services they provide to science and society. We owe a debt of gratitude to all of our staff, students, colleagues, volunteers, supporters, and administrators who made the success and productivity of the NSRL possible, either directly or indirectly, during the last 50 years. Thank you all.

NATURAL SCIENCE RESEARCH LABORATORY

Introduction

The Natural Science Research Laboratory (NSRL), a research and collections division of the Museum of Texas Tech University, was established in 1972 and officially opened its doors in 1973. Fifty years later, we look back at the accomplishments and contributions of the NSRL to Texas Tech University (TTU), the State of Texas, and to society (worldwide) through advancements in scientific research, graduate and undergraduate education, scholarly publication, leadership in natural history collections growth and curatorial management, and public engagement through exhibits and outreach activities.

To define the NSRL's position within Texas Tech University is difficult, as it is a unique entity in many ways.

- The NSRL is not an on-site research facility, per se, yet **curators, faculty, and their students have engaged in a broad spectrum of research endeavors**. Further, it has supported the research programs of affiliated faculty that have brought in **more than $25 million in external research awards and endowments** to TTU since 1996—awards that would not have been possible without the existence and resources of the NSRL.

- The NSRL is not a degree-granting entity, yet it **has enabled the research projects and education of more than 250 TTU graduate students and an estimated 500+ undergraduate students** directed by NSRL-affiliated faculty—resulting in scientific research, education, and scholarly output directly attributable to the NSRL. The success and achievements of these graduates in their careers speaks to the invaluable education, training, and experience that they received while involved in NSRL-based activities during their time at TTU.

- The NSRL does not have full-time research or teaching faculty, yet it has generated **>2,000 peer-reviewed scholarly publications** through its affiliated faculty (via their academic appointments), staff, and students while at TTU. Further, thousands of additional publications have resulted from faculty and students at other institutions that utilized NSRL specimens, tissues, and data in their research.

- As a natural history collections facility, the NSRL **is recognized nationally and internationally as a leader in curatorial science and collections management practices**. Throughout its history, the NSRL developed many of the policies, procedures, and accreditation standards that have been widely adopted by natural history collections. The NSRL also is lauded for its program of hands-on training of students in field biology and curatorial practices for future careers in natural history research and museum collections management. Further, the Mammal and GRC collections are among the largest and fastest growing such collections in North America. **Through this growth comes an increased importance and value as a resource for scientific research.**

- As a division of the Museum, the NSRL **engages and informs the public through exhibits related to biodiversity, conservation, TTU research endeavors, and the value of natural history collections, as well as two open-access publication series, a popular website, and direct outreach activities**. For many local and regional visitors, in particular, these exhibits and outreach activities may be the only opportunities they have to engage with science and natural history discovery.

Historical Overview of the NSRL's Collections

The NSRL currently is comprised of four primary collections—Mammals, Genetic Resources, Invertebrate Zoology, and Birds (see Appendix A: *Current Collection Profiles*). Many notable mammalogists have been affiliated with the NSRL throughout its history. Consequently, much of this 50-year report may seem biased toward that collection. However, the GRC is growing at a phenomenal rate, the Invertebrate Zoology collection is seeing a resurgence of activity through the attention of its new Acting Collections Manager, Dr. Jennifer Girón, and the Bird Collection represents a valuable reference collection of birds from Texas.

The **Mammal Collection** has been, and continues to be, particularly active and productive due to the research interests of TTU faculty who have focused primarily on mammals in their research programs. The collection began with the specimens collected by Dr. Robert L. Packard, who was hired in 1962 as the first mammalogist at Texas Tech University, and the mammal collection continued to grow after the hiring of Dr. Robert J. Baker in 1967. The collection originally was housed in the Department of Biology but was transferred to the basement of the current Museum building in 1971. At that time, the Mammal Collection contained nearly 15,000 specimens. The collection then was transferred to the new NSRL building in late 1973. The collection grew to 50,000 specimens by 1988, 100,000 specimens by 2003, and now numbers more than 156,500 specimens. In addition to Dr. Packard and Dr. Baker (Horn Professor), other notable Texas Tech mammalogists that grew the collection and


1


2

1. Dr. Robert L. Packard

2. Drs. Hugh H. Genoways and Robert J. Baker in the NSRL, 1974

served as curators, collection managers, or research associates over the past 50 years include Drs. Hugh H. Genoways, J. Knox Jones, Jr. (Horn Professor), Clyde Jones (Horn Professor), Dilford C. Carter, Stephen L. Williams, Robert D. Owen, Michael R. Willig, Ronald K. Chesser, Carleton J. Phillips, David J. Schmidly, Robert D. Bradley, Caleb D. Phillips, and Richard D. Stevens. These faculty and and staff members, as well as other TTU faculty members who are research associates of the NSRL, have actively utilized the mammal and genetic resource collections for scientific research, education of graduate and undergraduate students, and scholarly publications. The current curators of the Mammal Collection are Drs. Bradley and Stevens (see Appendix B: *Current Staff Profiles*).

Drs. Clyde Jones, Ronald Chesser, Robert Owen, Michael Willig, Robert Baker, Dilford Carter, and J. Knox Jones, Jr. (seated) at the cataloging of the NSRL's 40,000th mammal specimen in 1984.

The **Robert J. Baker Genetic Resources Collection (GRC) officially was established at the Museum in 1976** (at that time it was known as the "Living Tissues Collection") when frozen cell lines, cultured from living animals, were transferred from Dr. Baker's laboratory in the Department of Biology to the NSRL, and Dr. Baker was named as Curator of that collection. **No other museum was known to contain such a collection at that time**. When it was established, the collection was comprised of cell lines from more than three hundred mammal specimens. The samples were stored in liquid nitrogen in portable dewars or in -80°C ultracold freezers. As with the collections of traditional specimens, cell samples were available to other researchers through the NSRL's loan program for use in genetic, medical, biochemical, chromosomal, immunological, and other types of studies. The collection soon expanded to include whole-tissue samples, such as muscle, liver, heart, kidney, brain, blood, and many other tissue types, taken directly from field-collected specimens. The collection is estimated to have grown to 50,000 samples by 1996. By 2009, the GRC held more than 240,000 samples, and today that number has nearly doubled, with **a comprehensive inventory putting the number of samples at more than 470,000**.

First ultracold freezers (on right) at the NSRL

Although the majority of the samples in the GRC are frozen, the collection also contains non-frozen genetic samples such as karyotype slides, whole blood, tissues in lysis buffer, and isolated DNA and RNA, each maintained by methods appropriate for their preservation. The frozen tissues collection previously was housed in ultracold -80°C freezers, but the GRC was improved to a state-of-the-art liquid nitrogen (LN2) storage facility beginning in 2015. Currently, the GRC houses its 470,000+ genetic samples in six LN2 freezers, seven -80°C freezers for samples not suitable for liquid nitrogen, and various other storage units for non-frozen samples, **making it the second largest biorepository of its kind in terms of total samples, and one of the few such collections utilizing LN2 storage**. The NSRL collects more mammalian tissue types (8 to 13 different tissues per individual) than any other similar collection, thus expanding the research potential of the collection. Through the NSRL's loan program, these samples are available for research by TTU and non-TTU researchers worldwide. This collection also is mammal-centric, with about 95% of its samples being mammalian in nature; however, samples obtained from birds, invertebrates, and other taxonomic groups also are represented. Further, the addition of the Wolcott Wound Care Collection (microbiome samples obtained from human wounds) has broadened the research capacity of the NSRL. Dr. Baker remained Curator of the Genetic Resources Collection until his retirement in 2015, at which time Dr. Caleb D. Phillips was appointed as Curator (see Appendix B: *Current Staff Profiles*).

Also important to the university, the state of Texas, and the worldwide scientific community, the **Invertebrate Zoology Collection** of the NSRL holds an estimated **4.6 million specimens**. It is the largest collection of any type held by the Museum, and it is the **3rd largest invertebrate collection in Texas**. It contains especially significant collections of ants, medical and veterinary parasites, arachnids, rare species of beetles and butterflies confiscated by the US Fish and Wildlife Service, endangered cave spiders, a large collection of economically important species, and specimens collected in Texas national and state parks. The Invertebrate Zoology collection has a complex history, with components of the collection at times transferred to the purview of other departments on campus, before later returning to the NSRL facility. From the beginning, the Invertebrate Zoology collection focused on the arachnids and the cave fauna of the southwestern US and Mexico. By 1977, the collection contained an estimated 250,000 specimens of 100,000 species. Collection data for nearly 200,000 specimens is currently available online. Notable TTU faculty, curators, and staff that helped

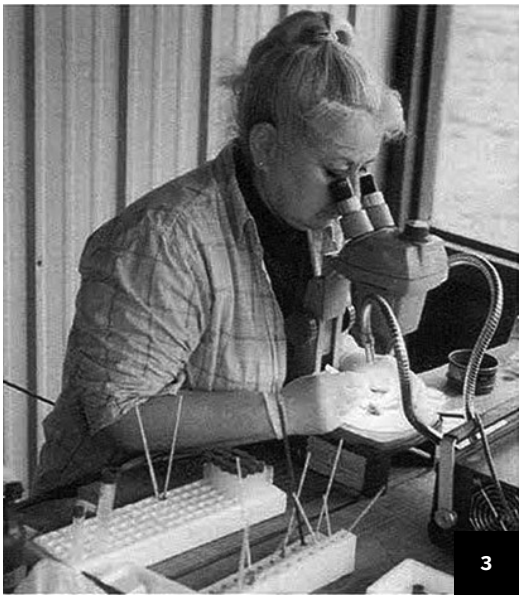
Liquid nitrogen freezers in the Genetic Resources Collection, 2015

1. Invertebrate specimens preserved in alcohol

2. Dried and pinned beetle specimens

3. Dr. Marilyn A. Houck

4. James C. Cokendolpher



to build the collection, managed the collection, and utilized the collection in their research and publications include Drs. Robert W. Mitchell, Oscar Franke, Robert W. Sites, Danny B. Pence, Marilyn A. Houck, and James C. Cokendolpher. Dr. Jennifer C. Girón is the current Acting Collections Manager (see Appendix B: *Current Staff Profiles*).

As with the Mammal Collection, the **Bird Collection** originally was housed in the Department of Biology and was transferred to the Museum basement in 1971 and then to the NSRL in 1973. At that time, the Bird Collection was comprised of about 1,000 specimens (600 skins and 400 in alcohol) and included the only significant representative collection of native species from the Llano Estacado in existence. By 1978, the collection contained approximately 3,000 study skins, as well as 300 sets of eggs. Currently, the Bird Collection is comprised of >6,000 specimens, including taxidermy mounts, as well as nests and eggs, and it is the **second largest bird collection in Texas**. In particular, its holdings represent an excellent reference collection of the incredibly diverse variety of birds (more than 660 species) known from Texas. The collection also contains species from almost every US state and at least 13 other countries. The collection originally was curated by faculty member Dr. M. Kent Rylander and currently is under the purview of Dr. Nancy E. McIntyre (see Appendix B: *Current Staff Profiles*).

Study skins of cardinals archived in the Bird Collection

Selection of taxidermy in the Bird Collection

Although not an accessioned collection, the NSRL also houses the Robert L. Packard Natural History Library. Established with the initial donation of Dr. Packard's research library of books and reprints (scientific articles) in 1979, the Packard Library has continued to grow with donations of the partial or complete research libraries of E. Lendell Cockrum, Dilford Carter, Stephen L. Williams, Marilyn Houck, J. Knox Jones Jr., Clyde Jones, Philip Krutzsch, Kent Rylander, Robert J. Baker, Ron Pine, Ronald K. Chesser, James C. Cokendolpher, David J. Schmidly, and more. The Library collection includes many rare books, gray literature, journals, and other data sources, as well as significant collections of photographs and slides, in the topics of mammalogy, ornithology, and invertebrate zoology. Very few academic natural history collections have a similar reference library of such size and historical significance that is available for use by faculty, staff, students, research associates, and visiting researchers, and this resource is a valuable asset of the NSRL.

1 & 2. A selection of rare and recent books in the Robert L. Packard Natural History Library

Research

Although this report focuses on five primary areas of productivity and achievement by the NSRL, research is the driving force behind all of these activities. Research results in, provides for, and depends upon—in various, interconnected ways—the education of students, scholarly publication, collections growth and advancements, and engagement and outreach activities. **For the past 50 years, research has been the foundation upon which the natural history collections of the NSRL were established, and research is the reason that the collections must be preserved at the highest level of care and must continue to grow, as their future value to science, education, and society is incalculable and unknowable**. As technological advancements in research methodology allow us to learn even more from these collections, and as the landscapes, climate, and biodiversity of Earth continue to change from both natural and human-caused factors, research will be the key to understanding these changes, making new discoveries, and finding new solutions. As a Tier One institution, Texas Tech University is committed to research as a primary focus of its mission. Throughout its history, the NSRL and its affiliated faculty-led research programs have contributed to the success of TTU as a research institution, and we share in TTU's commitment to becoming a top-50 research university.

RESEARCH FUNDING

Over its history, the NSRL has obtained research funding from numerous federal and state agencies, as well as NGOs and private donors. Although it has been difficult to determine the complete history of NSRL funding back to its founding, and because we have not translated award totals into today's dollars, the actual outside funding generated by the NSRL is unknown. However, based on the information we have been able to obtain, **at least $25 million in external research funding has been awarded to TTU that was made possible by the faculty and resources of the NSRL**.

The growth of the NSRL collections, the research projects utilizing these collections, and the resulting scientific discoveries and scholarly publications that are highlighted throughout this report largely were the direct result of federal, state, and other funding awarded to the numerous faculty mentioned in the *Historical Overview* section. However, due to the unique position of the NSRL (and Museum as a whole), the research awards received by these faculty members are credited to their home departments—primarily Biological Sciences, but also Natural Resources Management and others. Thus, the "value" of the NSRL to Texas Tech University in terms of research dollars generated—a metric that typically is seen by upper administration leaders of a university as most important when assessing the value of a department or facility—is misrepresented because credit is given to the academic departments of the PIs and Co-PIs. However, the awards made to these faculty members were for research directly related to, or dependent upon, the NSRL collections, and thus those awards **would not have been possible without the resources held and services provided by the NSRL**.

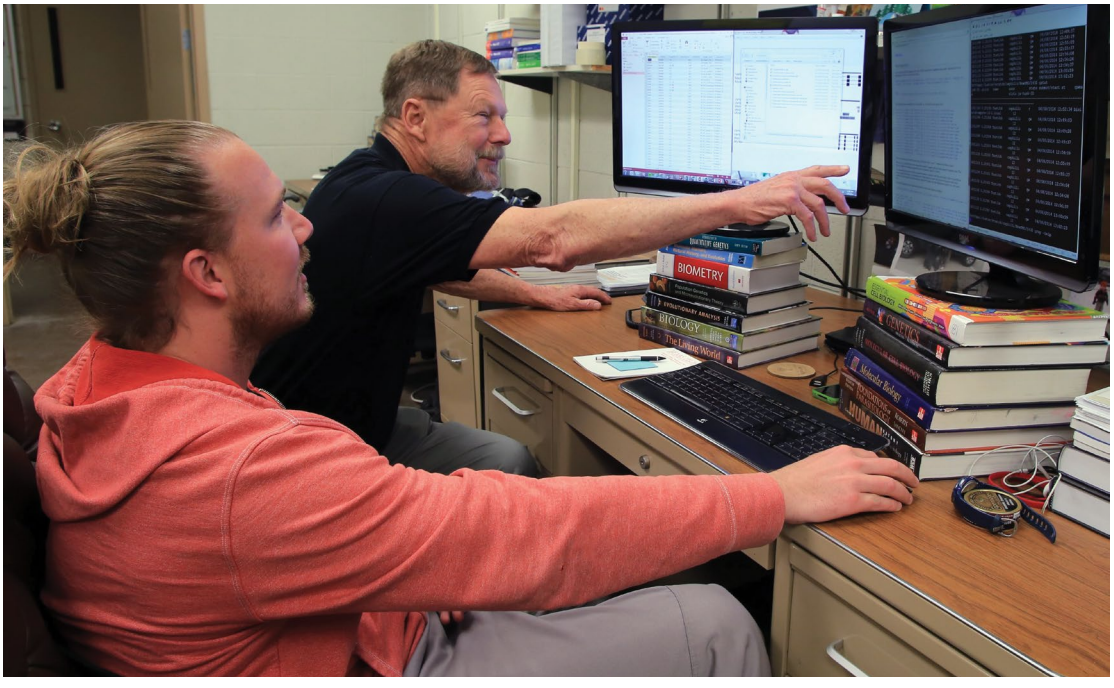
Despite this emphasis by universities and states on research funding, **the true value of scientific collections to science and society cannot be measured and is impossible to calculate**. No monetary value can be placed on the usefulness of a specimen or genetic sample for past, current, or future research

and teaching, and the subsequent benefits to society of that research, teaching, and scholarly output. It is our position that **this intrinsic value of an active and well-respected natural history collection is of significant merit and greatly benefits a university**, even though it cannot be directly calculated as dollar values on an accounting spreadsheet.

Herein, we have—to the best of our abilities—summarized the history of external funding received by NSRL-affiliated TTU faculty and staff for research based on NSRL specimens and samples. Older records (pre-1996) of such funding are sparse and in many cases were impossible to obtain or reassemble (pre-digital era written records have been lost or destroyed; former faculty are deceased and CVs are unavailable or incomplete, etc.). Therefore, the data below represent a number well below the total funding generated during the NSRL's 50-year history. Further, dollar figures have not been adjusted for inflation—clearly, a grant of $25,000 in 1975 was of far greater impact at that time than a grant of $25,000 today.

Dr. Robert J. Baker

In discussing funding and the NSRL, Dr. Robert J. Baker (Biological Sciences faculty 1967–2015, Curator of Mammals and the GRC 1976–2015, Coordinator for Research for the Museum 1976–1984, Director of the NSRL 1983–2015) must be singled out. Owing in part to his long tenure with TTU and as a Curator and Director of the NSRL, Dr. Baker was the single most productive researcher in terms of grants and contracts awarded for NSRL-based research and facility improvements. Over the course of his career, Dr. Baker received funding from at least 31 sources—federal agencies, state agencies, foreign agencies, foundations, conservation organizations, and private donors—for mammalogical research and NSRL collections enhancement, including 15 grants from the National Science Foundation (NSF).



Drs. Caleb Phillips and Robert Baker review results of DNA sequencing analyses of Phyllostomid bats based on GRC tissue samples.

Perhaps most impactful in terms of external support for the NSRL was Dr. Baker's success in procuring a State of Texas Line Item to create a Biological Database for the state of Texas. Initiated in 1996, this line item has resulted in a total of nearly $5.5 million in funding for the NSRL, to date. This funding has been devoted to the support of in-state research projects, student assistants working in the NSRL, and curatorial supplies to develop and maintain these important collections of specimens, tissues, and related data that serve to document the biological diversity of the State.

Since the establishment of the Line Item in 1996, faculty affiliated with the NSRL have leveraged that funding into an additional $5,680,139 of federal funding (e.g., NSF, NIH, USDA, DoD, DoE, USFWS), $3,934,905 of other state funding (e.g., TPWD, TxDOT, Texas Comptroller), and $8,783,649 in grants and donations from corporations, foundations, and individuals (e.g., CH Foundation, Helen Jones Foundation, Nature Conservancy, Texas Bighorn Sheep Society, Dr. Randall Wolcott, M.D., James Sowell, Ben E. Keith, Robert and Laura Baker). In total, including the Line Item, **TTU has received more than $23 million in external funding for NSRL-based research and education since 1996**. As mentioned above, the record of research funding awarded to the numerous faculty affiliated with the NSRL prior to 1996 (other than Dr. Baker) is incomplete, but is known to total a minimum of $2 million (not adjusted for inflation).

Another significant event during Dr. Baker's tenure as Director was the donation of funds from a private donor, James E. Sowell, that made possible multiple international collecting expeditions by the NSRL. From 2001 to 2007, Sowell funded collecting trips to Ecuador, Honduras, Mexico, Malaysia, Ukraine, and the Kyrgyz Republic. These expeditions resulted in valuable collections of mammal specimens and tissues in terms of taxonomic and geographic diversity and research value, as well as numerous scientific publications and educational experiences for dozens of students.

The NSRL has received at least four NSF grants (as well as private foundation grants) specifically to enhance the collections and facilities of the NSRL, as detailed here:

Cases being installed on compacting rails in the Mammal Collection, 2006

NSF, "Updating and Enhancement of the Recent Mammal Collections, Texas Tech University". 1986. Robert J. Baker. $131,000.

NSF, "Enhancement of Collections and Safety at the Museum, Texas Tech University". 1998. Robert J. Baker, Clyde Jones, David J. Schmidly, Richard E. Strauss, and Robert D. Bradley. $118,818.

Helen Jones Foundation, "Archival Museum Cases for Collections Storage and Expansion". 2005. Robert J. Baker. $292,500.

NSF, "Collection Enhancement, Enlargement, and Compactorization at the Natural Science Research Laboratory". 2006. Robert D. Bradley and Robert J. Baker. $224,999.

The CH Foundation, "Mechanical Assist System Installing/Retrofitting Project". 2015. Eileen Johnson, Robert D. Bradley, and Cameron Saffell. $37,751.

NSF, "Development of a Liquid Nitrogen System for the Genetic Resources Collection, Natural Science Research Laboratory, Museum of Texas Tech University". 2015. Robert J. Baker and Robert D. Bradley. $412,012.

More recently, a few of the federal and state grants received by NSRL-affiliated faculty and staff for biological research and for collections digitization (a major initiative of NSF and the scientific collections community) include:

TPWD, "Digitization of the bee (Hymenoptera: Anthophila) holdings at Texas Tech University with DNA barcoding for species of interest." 2022. Scott Longing, Jennifer Girón, and Joseph Manthey. $70,000.

USFWS/TPWD, "Survey of Tri-colored bat winter roost sites and associated White Nose syndrome in east and central Texas". 2022. Richard D. Stevens. $100,000.

TPWD, "Morphology, landscape genomics, and effective population size of the Palo Duro Mouse, *Peromyscus truei comanche*". 2022. Joseph Manthey, Caleb D. Phillips, and Robert D. Bradley. $239,316.

NSF, "Digitization PEN: BatPEN!-A partnership to facilitate scientific inquiry into the vast functional trait diversity of phyllostomid bats." 2021. Richard D. Stevens and Robert D. Bradley. $175,000.

GBIF, "Data mobilization for key entomological groups across Caribbean Colombia." 2021. Larry Jiménez-Ferbans, Jennifer Girón (collaborator). $40,000.

NIH, "Patient Genetic Determinants of Chronic Wound Microbiome Composition." 2021. Caleb D. Phillips. $421,373.

TPWD, "Assessing Texas Kangaroo Rat habitat connectivity, management, and monitoring protocols." 2021. Clint Boal, Richard D. Stevens, and C. Villalobos. $227,982.

TX Comptroller of Public Accounts, "Spatial ecology of the Texas Kangaroo Rat (*Dipodomys elator*)." 2020. Richard D. Stevens. $300,000.

NSF, "Community processes structuring assembly and disassembly of bat gut-microbial communities across a gradient of habitat degradation." 2018. Tigga Kingston and Caleb D. Phillips. $829,961.

TPWD, "Status, distribution, morphology and genetics of *Sigmodon fulviventer dalquesti* in the Chihuahuan Desert ecoregion." 2017. Caleb D. Phillips. $134,447.

TxDOT, "Endangered Eyeless *Cicurina* (Araneae: Dictynidae): Species Identification with Genetic Applications." 2014. Robert J. Baker, James C. Cokendolpher, Caleb D. Phillips. $89,717.

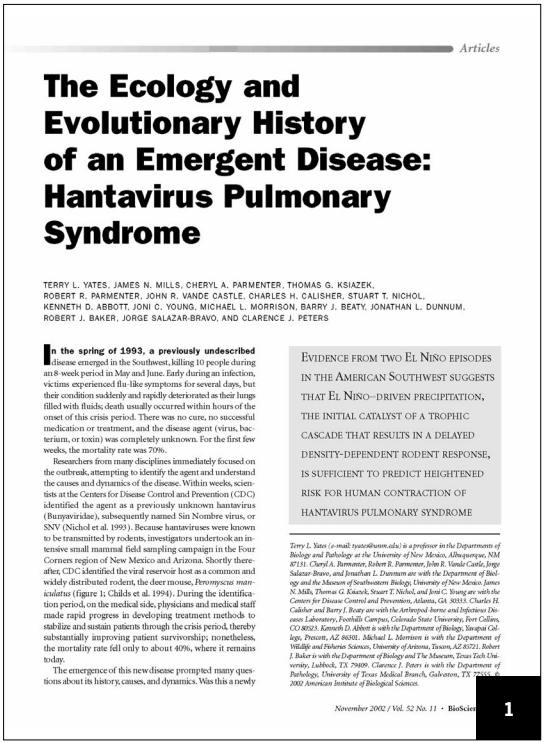
NSF, "Southwest Collections of Arthropods Network (SCAN): A Model for Collections Digitization to Promote Taxonomic and Ecological Research." 2012. James C. Cokendolpher. $155,461.

In 2016, Drs. Baker and Bradley received a grant of $250,000 from The CH Foundation to establish the "Endowment for Mammalian Research at the Natural Science Research Laboratory." The funds generated by that endowment have provided critical support for faculty and student research studies and for the growth and care of the mammal collection of the NSRL. In addition, several former faculty and associates of the NSRL have generously established endowments in support of the NSRL for research, student support, growth of the collections, and the continued high level of care and preservation of the collections. These include endowments established by: the Living Trust of the widow of Dr. Robert Packard, founder of the NSRL (Patricia J. Packard Laughlin Research Fund); Dr. David J. Schmidly, mammalogist, TTU alumni, and former TTU President (David J. and Janet Schmidly Research Endowment for the Studies of Texas Mammals); and Drs. Robert and Laura Baker, in support of the Genetic Resources Collection and GRC-based research and education (Bobby Baker Endowed Research Fund for Genomic Studies and the Bobby Baker Memorial Scholarship Endowment).

SCIENTIFIC RESEARCH ACTIVITIES

Research studies supported by external funding and conducted by NSRL-affiliated faculty and staff throughout its history have spanned a breadth of topics within the natural sciences. The topics investigated have ranged from basic natural history information, such as species distributions and conservation status, to systematic biology and taxonomy (including the discovery of multiple new species and subspecies of mammals and invertebrates), molecular evolution, chromosomal evolution, phylogenetics, community ecology, biogeography, morphology, population biology, ecotoxicology (including the effects of radiation, based on the Chernobyl collection), collections care and preservation, databasing and digitization, conservation genetics, zoonotic diseases, wildlife diseases, metagenomic and genomic evolution, microbiomes, biodiversity informatics, and more. The research results and impact generated by NSRL-affiliated faculty, staff, students, and collaborators using the collections archived in the NSRL are far too numerous and wide-ranging to summarize here. However, a selection of publications resulting from these research projects is highlighted in the *Scholarly Activities* section of this document, and those publications provide insight into the breadth of research made possible by the NSRL.

One example of the value of natural history collections for research that is of particular importance today is the study of zoonotic diseases. **Natural history collections play a vital role in understanding the hosts, vectors, geographic distribution, and temporal**



Articles

The Ecology and Evolutionary History of an Emergent Disease: Hantavirus Pulmonary Syndrome

TERRY L. YATES, JAMES N. MILLS, CHERYL A. PARMENTER, THOMAS G. KSIAZEK, ROBERT R. PARMENTER, JOHN R. VANDE CASTLE, CHARLES H. CALISHER, STUART T. NICHOL, KENNETH D. ABBOTT, JONI C. YOUNG, MICHAEL L. MORRISON, BARRY J. BEATY, JONATHAN L. DUNNUM, ROBERT J. BAKER, JORGE SALAZAR-BRAVO, AND CLARENCE J. PETERS

In the spring of 1993, a previously undescribed disease emerged in the Southwest, killing 10 people during an 8-week period in May and June. Early during an infection, victims experienced flu-like symptoms for several days, but their condition suddenly and rapidly deteriorated as their lungs filled with fluids; death usually occurred within hours of the onset of this crisis period. There was no cure, no successful medication or treatment, and the disease agent (virus, bacterium, or toxin) was completely unknown. For the first few weeks, the mortality rate was 70%.

Researchers from many disciplines immediately focused on the outbreak, attempting to identify the agent and understand the causes and dynamics of the disease. Within weeks, scientists at the Centers for Disease Control and Prevention (CDC) identified the agent as a previously unknown hantavirus (Bunyaviridae), subsequently named Sin Nombre virus, or SNV (Nichol et al. 1993). Because hantaviruses were known to be transmitted by rodents, investigators undertook an intensive small mammal field sampling campaign in the Four Corners region of New Mexico and Arizona. Shortly thereafter, CDC identified the viral reservoir host as a common and widely distributed rodent, the deer mouse, *Peromyscus maniculatus* (figure 1; Childs et al. 1994). During the identification period, on the medical side, physicians and medical staff made rapid progress in developing treatment methods to stabilize and sustain patients through the crisis period, thereby substantially improving patient survivorship; nonetheless, the mortality rate fell only to about 40%, where it remains today.

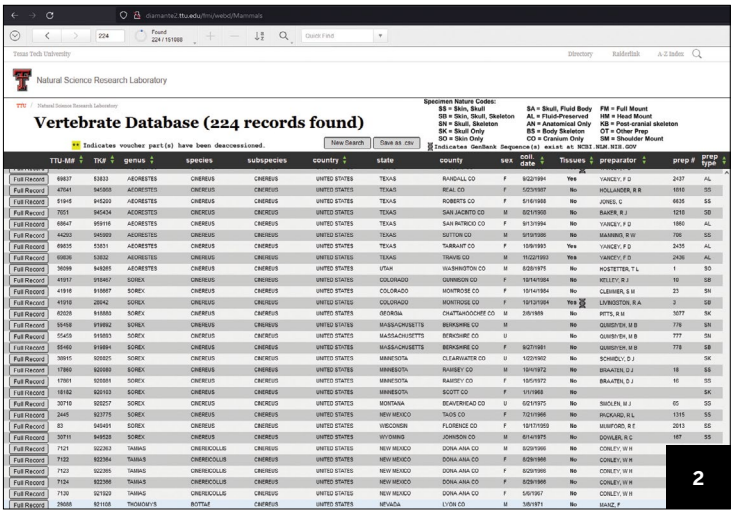
The emergence of this new disease prompted many questions about its history, causes, and dynamics. Was this a newly

EVIDENCE FROM TWO EL NIÑO EPISODES IN THE AMERICAN SOUTHWEST SUGGESTS THAT EL NIÑO–DRIVEN PRECIPITATION, THE INITIAL CATALYST OF A TROPHIC CASCADE THAT RESULTS IN A DELAYED DENSITY-DEPENDENT RODENT RESPONSE, IS SUFFICIENT TO PREDICT HEIGHTENED RISK FOR HUMAN CONTRACTION OF HANTAVIRUS PULMONARY SYNDROME

Terry L. Yates (e-mail: tyates@unm.edu) is a professor in the Departments of Biology and Pathology at the University of New Mexico, Albuquerque, NM 87131. Cheryl A. Parmenter, Robert R. Parmenter, John R. Vande Castle, Jorge Salazar-Bravo, and Jonathan L. Dunnum are with the Department of Biology and the Museum of Southwestern Biology, University of New Mexico. James N. Mills, Thomas G. Ksiazek, Stuart T. Nichol, and Joni C. Young are with the Centers for Disease Control and Prevention, Atlanta, GA 30333. Charles H. Calisher and Barry J. Beaty are with the Arthropod-borne and Infectious Diseases Laboratory, Foothills Campus, Colorado State University, Fort Collins, CO 80523. Kenneth D. Abbott is with the Department of Biology, Yavapai College, Prescott, AZ 86301. Michael L. Morrison is with the Department of Wildlife and Fisheries Sciences, University of Arizona, Tucson, AZ 85721. Robert J. Baker is with the Department of Biology and The Museum, Texas Tech University, Lubbock, TX 79409. Clarence J. Peters is with the Department of Pathology, University of Texas Medical Branch, Galveston, TX 77555.

history of emerging and reemerging zoonotic pathogens. For example, samples from Deermice that were archived in frozen tissue collections (including the NSRL and the Museum of Southwestern Biology, University of New Mexico) revealed that the previously unknown Sin Nombre virus, which caused the outbreak of hantavirus pulmonary syndrome in the American Southwest in the early-1990s, was not a new virus at all, but in fact had been present in wild mice for many years, and further, that weather patterns could predict periods of increased risk of hantavirus transmission to humans. The NSRL collections also have been used to describe several new strains of viruses, bacteria, and parasites that cause disease in animals and humans, including hantaviruses, arenaviruses, and a tick-borne encephalitis. These and other similar cases demonstrate the value of using materials deposited in natural history collections for such research, which is clearly becoming even more critical as the rate of zoonotic disease outbreaks are increasing as a consequence of human population growth, land use conversion, and global climate change.

The physical specimens and tissues in a natural history collection are only as valuable as the data that are associated with them. The date and location of their collection typically are the most vital data, but multiple other data points are recorded for each specimen and tissue. The data associated with the NSRL's specimens and tissues are available to the scientific community via its **online databases**. The databases are used by researchers for two primary purposes—to obtain comparative data to augment their research, and to determine the availability of specimens or tissues they wish to borrow for their research. By accessing a database, researchers can obtain data with regard to the geographic distribution of a species (locality occurrences), morphological data (measurements), and a wealth of additional natural history information. For certain types of studies, these data are sufficient for research purposes, without necessitating additional collecting of specimens and tissues, loans, or in-person visits to the collection. For those studies that do require in-person examination of specimens or analysis of NSRL tissues, **scientists at TTU and other institutions, museums, and agencies worldwide borrow mammal, bird, and invertebrate specimens and tissues for their research on multiple topics through the NSRL's active loan program**. Since 1991, the NSRL has processed 667 loan requests from the Mammal Collection and 1,788 loan requests from the Genetic



Natural Science Research Laboratory

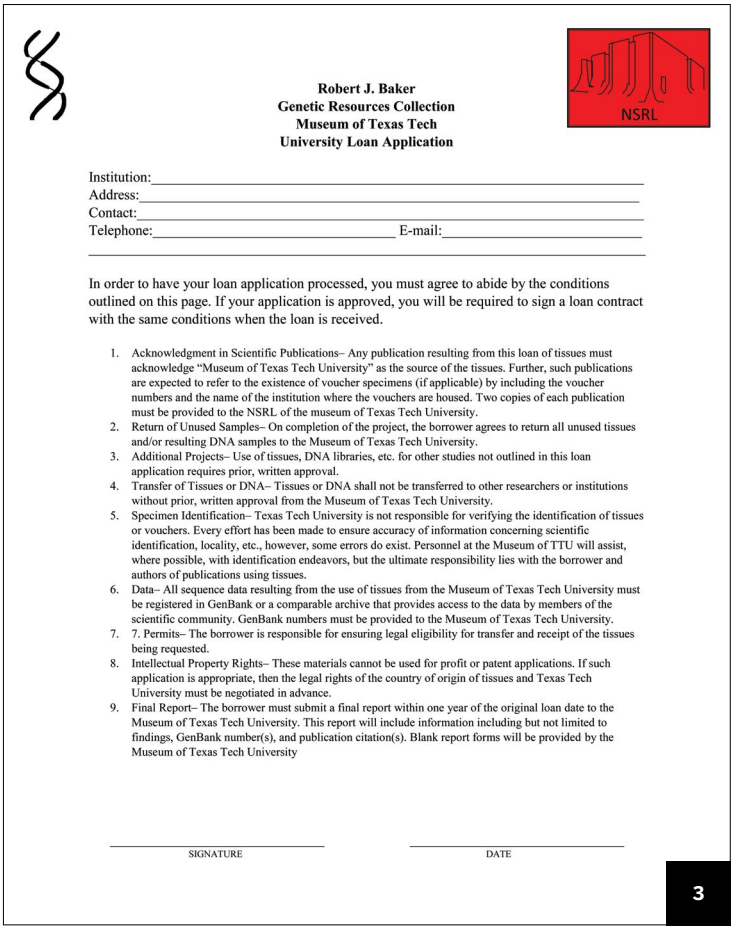
Vertebrate Database (224 records found)

Specimen Nature Codes:
SS = Skin, Skull
SB = Skin, Skull, Skeleton
SN = Skull, Skeleton
SK = Skull Only
SO = Skin Only
SA = Skull, Fluid Body
AL = Fluid-Preserved
AN = Anatomical Only
BS = Body Skeleton
CO = Cranium Only
FM = Full Mount
HM = Head Mount
KB = Post-cranial skeleton
OT = Other Prep
SM = Shoulder Mount

Indicates voucher part(s) have been deaccessioned. New Search | Save as .csv
Indicates GenBank Sequence(s) exist at NCBI NIH.NIH.GOV

	TTU-M#	TK#	genus	species	subspecies	country	state	county	sex	coll. date	Tissues	preparator	prep #	prep type
Full Record	69837	53833	AEORESTES	CINEREUS	CINEREUS	UNITED STATES	TEXAS	RANDALL CO	F	9/22/1994	Yes	YANCEY, F D	2437	AL
Full Record	47641	945868	AEORESTES	CINEREUS	CINEREUS	UNITED STATES	TEXAS	REAL CO	F	5/23/1997	No	HOLLANDER, R R	1616	SS
Full Record	51945	945200	AEORESTES	CINEREUS	CINEREUS	UNITED STATES	TEXAS	ROBERTS CO	F	5/16/1998	No	JONES, C	6636	SS
Full Record	7051	945434	AEORESTES	CINEREUS	CINEREUS	UNITED STATES	TEXAS	SAN JACINTO CO	M	6/21/1960	No	BAKER, R J	1216	SB
Full Record	69647	953116	AEORESTES	CINEREUS	CINEREUS	UNITED STATES	TEXAS	SAN PATRICIO CO	F	9/13/1994	No	YANCEY, F D	1860	AL
Full Record	44293	945069	AEORESTES	CINEREUS	CINEREUS	UNITED STATES	TEXAS	SUTTON CO	M	9/19/1986	No	MANNING, R W	706	SS
Full Record	69635	53831	AEORESTES	CINEREUS	CINEREUS	UNITED STATES	TEXAS	TARRANT CO	F	10/9/1993	Yes	YANCEY, F D	2435	AL
Full Record	69636	53832	AEORESTES	CINEREUS	CINEREUS	UNITED STATES	TEXAS	TRAVIS CO	M	11/22/1993	Yes	YANCEY, F D	2436	AL
Full Record	36999	945085	AEORESTES	CINEREUS	CINEREUS	UNITED STATES	UTAH	WASHINGTON CO	M	8/28/1975	No	HOFSTETTER, T L	1	SO
Full Record	41917	915467	SOREX	CINEREUS	CINEREUS	UNITED STATES	COLORADO	GUNNISON CO	F	10/14/1984	No	KELLEY, R J	10	SB
Full Record	41916	915887	SOREX	CINEREUS	CINEREUS	UNITED STATES	COLORADO	MONTROSE CO	F	10/14/1984	No	CLEBNER, S M	23	SN
Full Record	41910	28042	SOREX	CINEREUS	CINEREUS	UNITED STATES	COLORADO	MONTROSE CO	F	10/12/1984	Yes	LIVINGSTON, R A	3	SB
Full Record	60028	916883	SOREX	CINEREUS	CINEREUS	UNITED STATES	GEORGIA	CHATTAHOOCHEE CO	M	2/6/1989	No	PITTS, R M	3077	SK
Full Record	55458	916892	SOREX	CINEREUS	CINEREUS	UNITED STATES	MASSACHUSETTS	BERKSHIRE CO	M		No	QUINSIGH, M B	776	SN
Full Record	55459	916883	SOREX	CINEREUS	CINEREUS	UNITED STATES	MASSACHUSETTS	BERKSHIRE CO	U		No	QUINSIGH, M B	777	SN
Full Record	55460	916894	SOREX	CINEREUS	CINEREUS	UNITED STATES	MASSACHUSETTS	BERKSHIRE CO	F	6/27/1981	No	QUINSIGH, M B	778	SB
Full Record	36915	920825	SOREX	CINEREUS	CINEREUS	UNITED STATES	MINNESOTA	CLEARWATER CO	U	1/22/1962	No	SCHMIDLY, D J		SK
Full Record	17860	920880	SOREX	CINEREUS	CINEREUS	UNITED STATES	MINNESOTA	RAMSEY CO	M	10/4/1972	No	BRAATEN, D J	18	SS
Full Record	17861	920881	SOREX	CINEREUS	CINEREUS	UNITED STATES	MINNESOTA	RAMSEY CO	F	10/5/1972	No	BRAATEN, D J	16	SS
Full Record	19182	920193	SOREX	CINEREUS	CINEREUS	UNITED STATES	MINNESOTA	SCOTT CO	F	1/1/1968	No			SK
Full Record	30716	920257	SOREX	CINEREUS	CINEREUS	UNITED STATES	MONTANA	BEAVERHEAD CO	U	6/21/1975	No	SHOLEN, M J	65	SS
Full Record	2445	923775	SOREX	CINEREUS	CINEREUS	UNITED STATES	NEW MEXICO	TAOS CO	F	7/21/1966	No	PACKARD, R L	1315	SS
Full Record	83	949491	SOREX	CINEREUS	CINEREUS	UNITED STATES	WISCONSIN	FLORENCE CO	F	10/17/1950	No	MUMFORD, R E	2013	SS
Full Record	30711	949528	SOREX	CINEREUS	CINEREUS	UNITED STATES	WYOMING	JOHNSON CO	M	6/14/1975	No	DOWLER, R C	167	SS
Full Record	7121	922363	TAMIAS	CINEREICOLLIS	CINEREUS	UNITED STATES	NEW MEXICO	DONA ANA CO	M	8/29/1966	No	CONLEY, W H		
Full Record	7122	922364	TAMIAS	CINEREICOLLIS	CINEREUS	UNITED STATES	NEW MEXICO	DONA ANA CO	F	8/29/1966	No	CONLEY, W H		
Full Record	7123	922365	TAMIAS	CINEREICOLLIS	CINEREUS	UNITED STATES	NEW MEXICO	DONA ANA CO	F	8/29/1966	No	CONLEY, W H		
Full Record	7124	922366	TAMIAS	CINEREICOLLIS	CINEREUS	UNITED STATES	NEW MEXICO	DONA ANA CO	F	8/29/1966	No	CONLEY, W H		
Full Record	7120	921929	TAMIAS	CINEREICOLLIS	CINEREUS	UNITED STATES	NEW MEXICO	DONA ANA CO	F	5/6/1967	No	CONLEY, W H		
Full Record	29688	931108	THOMOMYS	BOTTAE	CINEREUS	UNITED STATES	NEVADA	LYON CO	M	3/6/1971	No	HANZ, F		

2



Robert J. Baker
Genetic Resources Collection
Museum of Texas Tech
University Loan Application

Institution:_____
Address:_____
Contact:_____
Telephone:_____ E-mail:_____

In order to have your loan application processed, you must agree to abide by the conditions outlined on this page. If your application is approved, you will be required to sign a loan contract with the same conditions when the loan is received.

1. Acknowledgment in Scientific Publications– Any publication resulting from this loan of tissues must acknowledge "Museum of Texas Tech University" as the source of the tissues. Further, such publications are expected to refer to the existence of voucher specimens (if applicable) by including the voucher numbers and the name of the institution where the vouchers are housed. Two copies of each publication must be provided to the NSRL of the museum of Texas Tech University.
2. Return of Unused Samples– On completion of the project, the borrower agrees to return all unused tissues and/or resulting DNA samples to the Museum of Texas Tech University.
3. Additional Projects– Use of tissues, DNA libraries, etc. for other studies not outlined in this loan application requires prior, written approval.
4. Transfer of Tissues or DNA– Tissues or DNA shall not be transferred to other researchers or institutions without prior, written approval from the Museum of Texas Tech University.
5. Specimen Identification– Texas Tech University is not responsible for verifying the identification of tissues or vouchers. Every effort has been made to ensure accuracy of information concerning scientific identification, locality, etc., however, some errors do exist. Personnel at the Museum of TTU will assist, where possible, with identification endeavors, but the ultimate responsibility lies with the borrower and authors of publications using tissues.
6. Data– All sequence data resulting from the use of tissues from the Museum of Texas Tech University must be registered in GenBank or a comparable archive that provides access to the data by members of the scientific community. GenBank numbers must be provided to the Museum of Texas Tech University.
7. 7. Permits– The borrower is responsible for ensuring legal eligibility for transfer and receipt of the tissues being requested.
8. Intellectual Property Rights– These materials cannot be used for profit or patent applications. If such application is appropriate, then the legal rights of the country of origin of tissues and Texas Tech University must be negotiated in advance.
9. Final Report– The borrower must submit a final report within one year of the original loan date to the Museum of Texas Tech University. This report will include information including but not limited to findings, GenBank number(s), and publication citation(s). Blank report forms will be provided by the Museum of Texas Tech University

SIGNATURE _____ DATE _____

3

1. A paper regarding hantavirus pulmonary syndrome, coauthored by Dr. Robert J. Baker and Dr. Jorge Salazar-Bravo of Texas Tech University.

2. Screenshot of an NSRL Mammal Database search.

3. A loan application for borrowing tissues from the Genetic Resources Collection.

Collecting bats in a mist net for research purposes

Drawing blood from a bighorn ram for disease research

Resources Collection. Since 1986, the Invertebrate Zoology Collection has made more than 100 loans to institutions such as Texas A&M, California Academy of Sciences, Field Museum of Natural History, American Museum of Natural History, Harvard University, and many others. Borrowers not only use the specimens for their research, but they frequently provide revised identifications, thus updating and improving the scientific value of the NSRL collections.

The NSRL's faculty, staff, and student researchers, archived collections, loan services, and online databases all **support the vital research mission of Texas Tech University, and benefit the worldwide scientific community and society. The importance of the collections continues to increase** as it is in demand for an ever-wider range of research areas, including research critical to not only biodiversity and the health of the planet, but to human health and society.

Graduate and Undergraduate Education

Graduate and undergraduate students in Biological Sciences and other departments have relied on the collections of the NSRL for their thesis and dissertation research since 1964, eight years before the NSRL facility was officially established. Those theses and dissertations were produced by students utilizing the early mammal collections that were held by the Department of Biological Sciences since 1962, when Dr. Robert Packard was hired as the first mammalogist at TTU. Dr. Packard brought his collection of specimens from his former institution, Stephen F. Austin State University, and trained his TTU graduate students on fieldwork and in specimen-based research, growing the collection and forming the foundation of what would become the NSRL. Dr. Robert J. Baker joined the faculty of Biological Sciences in 1967, and quickly began building his own collection of mammal specimens as well as karyotypes (chromosomal material from the bone marrow of mammals), cell lines, and tissues. Thus, even before the NSRL was officially established, these collections of specimens, cell lines, karyotypes, and tissue samples were being used by TTU students in their thesis and dissertation research.

Almost every graduate and undergraduate student working under the direction of Dr. Packard, Dr. Baker, and all the other mammalian-research faculty of TTU to follow have used the mammal collections of specimens and tissues of the pre-NSRL and NSRL as the basis for their research projects and have conducted fieldwork to grow the collections. Since 1964 (first student of Dr. Packard to graduate), **at least 140 Masters degrees and 115 PhDs have been obtained by TTU students that directly used the mammal, bird, invertebrate, and/or GRC collections held by the NSRL**. (We acknowledge that degrees granted based on use of the NSRL's Bird and Invertebrate Zoology collections are likely undercounted.) Currently, at least 9 Master's and 17 PhD students at TTU are utilizing the collections of the NSRL for their thesis and dissertation research.

In addition to the NSRL's record of producing quality graduate students, an estimated minimum of **500 undergraduate students** have utilized the NSRL collections to conduct research and to gain technical skills under the supervision of NSRL-affiliated faculty and staff. In recent years, 30 to 40 undergraduate students per year have worked in the laboratories of NSRL-affiliated faculty, conducted research using NSRL specimens and tissues, gained experience in fieldwork (collecting and preparing museum specimens), and received training in museum practices in the natural sciences. In another example of the impact of the NSRL on TTU students, many of the

Dr. Robert J. Baker with his final two PhD students, 2015

An undergraduate scholar in the laboratory of Dr. Robert D. Bradley.

dry-pinned specimens of the Invertebrate Zoology collection were collected and prepared by students taking entomology courses. Thus, the students gain hands-on experience in scientific collecting, specimen preparation, museum practices, digitization, and more, while enhancing the collection's representation of local fauna.

One of the factors that makes the NSRL so unique and valuable, particularly for mammalian-based research, is the combination of field-, museum-, and lab-based research and training that graduate and undergraduate students receive. NSRL-affiliated mammalogy faculty, almost always accompanied by students, have actively conducted fieldwork in the southwestern US, Mexico, Central and South America, the Caribbean, Ukraine, Kyrgyzstan, Malaysia, and numerous other countries, collecting specimens and/or tissues for deposit in the NSRL and for use in their research projects. In the field, the students are trained in preparing specimens for deposit in a natural history museum and properly recording data. Students also often work in the NSRL as part of their graduate or undergraduate student experience, thus learning the curatorial process from the moment a specimen is collected and field-prepped and throughout the process of cleaning and labeling bones, tagging and cataloging specimens, entering data into a database, and placing specimens or tissues into their appropriate, recorded locations in cabinets or freezers. Finally, the students use the specimens and tissues in research projects conducted in the laboratories of their faculty mentors, and co-author publications based on their research. **Few US universities provide graduate and undergraduate students with such broad training and experience in all aspects of natural history collecting, curating, and research, with an emphasis on mammalian studies**. Together, the scientific training and experience received by these students, from field to museum to laboratory, broadens their curriculum vitae and their career options in academia, governmental agencies, museums, and NGOs.

Graduates of TTU that used the NSRL as a resource for their research and education have held positions at the Centers for Disease Control, National Science Foundation, Defense Threat Reduction Agency, Harvard, Duke Medical School, Yale Medical School, Penn State, Purdue, Texas A&M University, University of New Mexico, Oklahoma State, Los Alamos National Laboratory, Smithsonian Institution, American Museum of Natural History, Field Museum, and many other prestigious institutions in the U.S. and abroad. **As a consequence of the success of these students and the reputation of the NSRL, TTU is often referred to as the "best place to obtain a graduate degree in mammalian biology."**

The total number of students, worldwide, impacted by the NSRL collections over the past 50 years is impossible to determine. Through the loan program of the NSRL, researchers at other institutions can borrow specimens and tissue samples for their research. Those researchers are directing graduate and undergraduate students that use the NSRL resources, resulting in theses, dissertations, publications, and graduates that are trained for careers in science and education. **Thus, the impact of the NSRL on education and science is significant beyond the already impressive reputation and accomplishments of the Texas Tech students that come directly through the NSRL**.

The American Society of Mammalogists has granted a total of 62 Shadle Awards and ASM Fellowships—their highest student honors—to graduate students since 1972. Texas Tech students have won 11 of these awards, just one fewer than the most-awarded institution. Graduate and undergraduate students also have received numerous awards for their research presentations at local, state, regional, national, and

Dr. Richard Stevens and students preparing mammal specimens in the field.

Dr. Robert Bradley and students show their TTU pride after a good night's catch of rodents in Mexico.

international meetings of scientific societies, such as the Texas Society of Mammalogists, American Society of Mammalogists, North American Society for Bat Research, and many others.

In addition to the graduate and undergraduate students discussed above, TTU students learn about the activities and value of the NSRL through tours of the facility as part of their courses in Mammalogy, Natural History of the Vertebrates, Ornithology, and Nongame Ecology. Faculty members also obtain loans of specimens from the NSRL for teaching these courses and others, such as Insect Diversity. Even faculty members in the School of Art, as part of an Honors College program of interdisciplinary studies in nature and the arts, borrow specimens for use as models in their classes. Specimen loans for teaching provide hands-on materials for students to learn about species identification, anatomy and physiology, functional adaptations, evolution, and more. After their introduction to the NSRL through these experiences, many students choose to expand their educational opportunities outside of class by volunteering or working at the NSRL, or even to pursue an advanced degree with an NSRL-affiliated faculty mentor. Further, students that are awarded Bobby Baker Scholarships through the Department of Biological Sciences broaden their academic training by spending 20 volunteer hours per month assisting in the Genetic Resources Collection.

The graduate and undergraduate students that have interacted with the NSRL through their research, coursework, employment, or volunteer activities have been among the best and brightest at TTU. Many of these students have been members of the Honors College, Howard Hughes Medical Institute scholars, CISER scholars, and recipients of Bobby Baker, Pi², Michelle Knapp, and other scholarships.

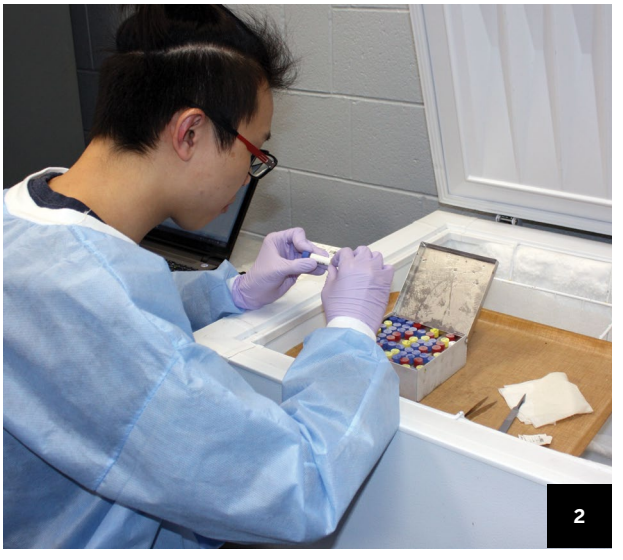
1

1. Nicté Ordóñez-Garza being introduced as winner of the Shadle Award, the highest student honor granted by the American Society of Mammalogists.

2. A student assistant processing samples in the Genetic Resources Collection.

3. A student digitizing specimens in the Invertebrate Zoology Collection.

The success of a university's students is paramount to the reputation of that university. Throughout its history, **the NSRL has been recognized for the vital role it plays, and the significant impact it has, on the education, training, and career success of the students that come out of the natural science and museum science programs at Texas Tech University**. The learning experiences our students gain through fieldwork and laboratory research while associated with the NSRL have lifelong impacts, both personally and professionally, and the notable contributions of these graduates to science and society throughout their careers are directly attributable to those experiences.


2


3

4

5

4. A busy "prep" session—students preparing bat and mountain lion specimens for the Mammal Collection.

5. Dr. Richard D. Stevens and students—a bright group of future researchers, teachers, and science professionals!

Scholarly Activities

The publication record of university faculty often is regarded as one of the most important metrics of individual and institutional success. Since 1972, NSRL-affiliated faculty, staff, and students have published an estimated **2,000+ peer-reviewed scientific papers**. For example, more than 320 papers have been published by NSRL-affiliated faculty, staff, and students from 2015 to present, nearly all of which resulted directly from the use of NSRL specimens and tissues. Dr. Robert J. Baker's bibliography, alone, numbers more than 450 papers published over a career of 48+ years. Significantly, nearly every paper published by NSRL-affiliated faculty was co-authored by one or more graduate and/or undergraduate students. Of the many publications produced by NSRL-affiliated faculty and students, below we highlight a few of the topics and papers that have been of especially significant impact to science.

Two papers by Drs. Robert J. Baker and Robert D. Bradley are regarded as classics on the topic of speciation. These publications have been cited more than 1,800 times in other scientific papers, to date.

Baker, Robert J., and R. D. Bradley. 2006. Speciation in mammals and the genetic species concept. Journal of Mammalogy 87:643-662.

Bradley, Robert D., and Robert J. Baker. 2001. A test of the genetic species concept: cytochrome-b sequences and mammals. Journal of Mammalogy 82:960-973.

Journal of Mammalogy, 87(4):643–662, 2006

SPECIATION IN MAMMALS AND THE GENETIC SPECIES CONCEPT

ROBERT J. BAKER* AND ROBERT D. BRADLEY

Department of Biological Sciences and the Museum, Texas Tech University, Lubbock, TX 79409-3131, USA

We define a genetic species as a group of genetically compatible interbreeding natural populations that is genetically isolated from other such groups. This focus on genetic isolation rather than reproductive isolation distingaishes the Genetic Species Concept from the Biological Species Concept. Recognition of species that are genetically isolated (but not reproductively isolated) results in an enhanced understanding of biodiversity and the nature of speciation as well as speciation-based issues and evolution of mammals. We review criteria and methods for recognizing species of mammals and explore a theoretical scenario, the Bateson–Dobzhansky–Muller (BDM) model, for understanding and predicting genetic diversity and speciation in mammals. If the BDM model is operating in mammals, then genetically defined phylogroups would be predicted to occur within species defined by morphology, and phylogroups experiencing stabilizing selection will evolve genetic isolation without concomitant morphological diversification. Such species will be undetectable using classical skin and skull morphology (Morphological Species Concept). Using cytochrome-*b* data from sister species of mammals recognized by classical morphological studies, we estimated the number of phylogroups that exist within mammalian species and hypothesize that there will be >2,000 currently unrecognized species of mammals. Such an underestimation significantly affects conclusions on the nature of speciation in mammals, barriers associated with evolution of genetic isolation, estimates of biodiversity, design of conservation initiatives, zoonoses, and so on. A paradigm shift relative to this and other speciation-based issues will be needed. Data that will be effective in detecting these "morphologically cryptic genetic species" are genetic, especially DNA-sequence data. Application of the Genetic Species Concept uses genetic data from mitochondrial and nuclear genomes to identify species and species boundaries, the extent to which the integrity of the gene pool is protected, nature of hybridization (if present), and introgression. Genetic data are unique in understanding species because the use of genetic data 1) can quantify genetic divergence from different aspects of the genome (mitochondrial and nuclear genes, protein coding genes, regulatory genes, mobile DNA, microsatellites, chromosomal rearrangements, heterochromatin, etc.); 2) can provide divergence values that increase with time, providing an estimate of time since divergence; 3) can provide a population genetics perspective; 4) is less subject to convergence and parallelism relative to other sets of characters; 5) can identify monophyly, sister taxa, and presence or absence of introgression; and 6) can accurately identify hybrid individuals (kinship and source of hybrid individuals, F_{1}s, backcrosses, direction of hybridization, and in concert with other data identify which hybrids are sterile or fertile). The proposed definition of the Genetic Species Concept is more compatible with a description of biodiversity of mammals than is "reproductively isolated species." Genetic profiles of mammalian species will result in a genetic description of species and mammalian diversity, and such studies are being accelerated by technological advances that reduce cost and increase speed and efficiency of generating genetic data. We propose that this genetic revolution remain museum- and voucher specimen–based and that new names are based on a holotype (including associated tissues) deposited in an accredited museum.

Key words: Bateson–Dobzhansky–Muller model, cryptic species, cytochrome *b*, genetic isolation, Genetic Species Concept, hybrid zones, phylogroups, reproductive isolation, speciation in mammals

Taxonomic and systematic literature pertaining to issues concerning species, speciation models, and whether species even exist in nature is voluminous. Even if one restricts the review to vertebrates and narrows the topics to species concepts and how to theoretically recognize species, the literature is impressive (e.g., Claridge et al. 1997; Coyne and Orr 2004; Howard and Berlocher 1998; Wheeler and Meier 2000).

643

* *Correspondent: rjbaker@ttu.edu*

Journal of Mammalogy, 82(4):960–973, 2001

A TEST OF THE GENETIC SPECIES CONCEPT: CYTOCHROME-*b* SEQUENCES AND MAMMALS

ROBERT D. BRADLEY* AND ROBERT J. BAKER

Department of Biological Sciences and Museum of Texas Tech University, Lubbock, TX 79409

Levels of sequence variation in mitochondrial cytochrome-*b* gene were examined to ascertain if this molecule can provide a reference point in making decisions concerning species-level distinctions. DNA-sequence data from 4 genera of rodents (*Neotoma, Reithrodontomys, Peromyscus,* and *Sigmodon*) and 7 genera of bats (*Artibeus, Carollia, Chiroderma, Dermanura, Glossophaga, Rhinophylla,* and *Uroderma*), including recognized sister species, were examined to develop hypotheses for evaluating levels of sequence variation. Several patterns associated with DNA-sequence variation emerged from this study. Specifically, genetic distance values <2% were indicative of intraspecific variation; values between 2 and 11% had a high probability of being indicative of conspecific populations or valid species and merit additional study concerning specific status; and values >11% were indicative of specific recognition. It appears that genetic distance values may be useful for determination of species boundaries under the framework of the Genetic Species Concept.

Key words: cytochrome-*b* sequences, Genetic Species Concept, mammals, molecular systematics

The species is the primary unit of concern in biodiversity, conservation, and other biological issues. Recent estimates of the number of species range from 10 to 100 million (Wilson 1998). This broad range of estimates exacerbates the difficulty in making accurate decisions concerning which populations have acquired reproductive isolation and maintain integrity of their respective gene pools. Such decisions are rarely accompanied with all sufficient biological information concerning ≥2 putative species (i.e., sympatric distributions, overlapping breeding seasons, fixed levels of genetic differentiation, complete fossil record, geological events and history, and time since divergence). Rather, in the process of determining the validity of putative species, systematists generally rely on indirect information in the form of some character system(s) (e.g., variation in size and shape of morphologic characters, cytogenetics, allozymes, DNA sequences). In reality, or at least in practice, the end product is a working definition of the species concept based on that particular set of characters.

To date, biologists have developed ≥22 species concepts (Mayden 1997) to describe and categorize biological diversity. This voluminous literature is accompanied by an ever-growing literature that discusses and tests merits and flaws of each concept. Although there usually is considerable debate among systematists as to the exact boundaries and utility of these working "species concepts" for various types of characters, most lists of species (classifications) are products of the application of combinations of these working "species concepts."

One of the lesser-known concepts, the Genetic Species Concept (sensu Dobzhansky 1950; Mayr 1969; Simpson 1943), is a measurement of genetic differences used to infer reproductive isolation and evolutionary independence (Mayden 1997). One criticism of the Genetic Species Concept is in

960

* *Correspondent: rbradley@ttacs.ttu.edu*

Two seminal papers regarding the Genetic Species Concept, authored by Drs. Robert Bradley and Robert Baker.

Through the efforts of researchers at the NSRL, there have been major contributions in the areas of systematics, taxonomy, and classification of rodents and bats, in particular, as these groups historically have been the areas of expertise of the NSRL curators and the strengths of the Mammal Collection. For example, the 3-volume set on Phyllostomatidae (the leaf-nosed bats), authored by Robert J. Baker, J. Knox Jones, Jr., and Dilford Carter, is recognized as one of the premiere works on New World bats (Biology of Bats of the New World Phyllostomatidae, *Special Publications* Volume 10, 1976; Volume 13, 1977; Volume 16, 1979). Similarly, Dilford Carter and his student Patricia Dolan contributed significantly to the classification of the Mollosidae (Systematics of Middle American Mastiff Bats of the Genus *Molossus*, *Special Publications* Volume 29, 1989).

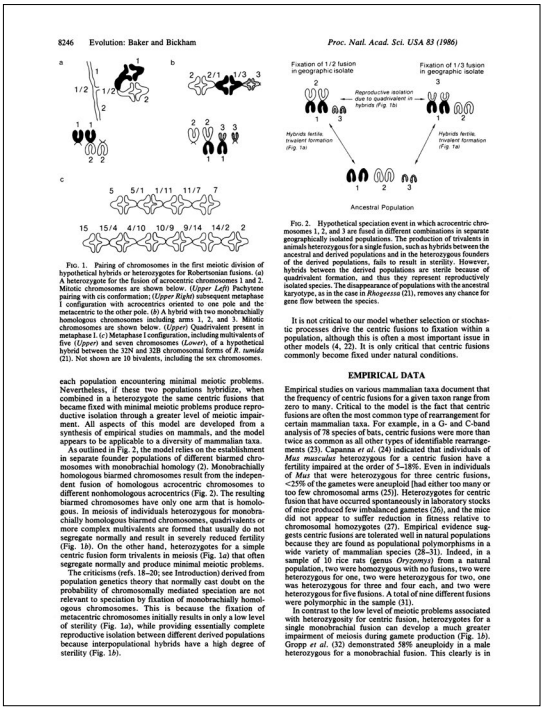
With regard to systematic and taxonomic studies of rodents, Drs. Bradley and Baker, in particular, have produced hundreds of publications. A particular research focus of Dr. Bradley has been the systematics of the genus *Peromyscus*, a particularly speciose, abundant, and wide-ranging group of North American mice. Dr. Bradley's vita includes at least 40 publications specifically about *Peromyscus*, as well as numerous publications on the systematics of other rodent groups such as pocket gophers and woodrats. Dr. Bradley's expertise in these areas is recognized by others in the scientific community. For example, Dr. Bradley, Dr. Nicté Ordóñez-Garza (former student of Dr. Bradley), and Lisa Bradley were invited to coauthor 133 species accounts in the 2017 work *Handbook of the Mammals of the World*, Volume 7, edited by Dr. Don Wilson and others. Similarly, Dr. Gerardo Ceballos, a leading mammalogist in Mexico, invited Dr. Bradley to coauthor multiple accounts for Cricetid rodents in his book, *The Mammals of Mexico* (2014).

Dr. Baker's bibliography contains too many examples of significant contributions to mammalian science to discuss them all in this report. His professional obituary (*Journal of Mammalogy*, 2018, 99:983-1012) and the memorial volume published in his honor (*Special Publications of the Museum*, 2019, Vol. 71) provide thorough discussions of the impact of his career in terms of published research. However, Dr. Baker's publications on chromosomal evolution, coauthored with Dr. John Bickham, were among his most significant during his early career. These include:

Bickham, J. W., and R. J. Baker. 1979. Canalization model of chromosomal evolution. Pp. 70–84 in Models and methodologies in evolutionary theory (J. H. Schwartz and H. B. Rollins, eds.). Bulletin of the Carnegie Museum of Natural History 13:70–84.

Baker, R. J., and J. W. Bickham. 1980. Karyotypic evolution in bats: evidence of extensive and conservative chromosomal evolution in closely related taxa. Systematic Zoology 29:239–253.

Baker, R. J., and J. W. Bickham. 1986. Speciation by monobrachial centric fusions. Proceedings of the National Academy of Science 83:8245–8248.



8246 Evolution: Baker and Bickham

Proc. Natl. Acad. Sci. USA 83 (1986)

FIG. 1. Pairing of chromosomes in the first meiotic division of hypothetical hybrids or heterozygotes for Robertsonian fusions. (*a*) A heterozygote for the fusion of acrocentric chromosomes 1 and 2. Mitotic chromosomes are shown below. (*Upper Left*) Pachytene pairing with cis conformation; (*Upper Right*) subsequent metaphase I configuration with acrocentrics oriented to one pole and the metacentric to the other pole. (*b*) A hybrid with two monobrachially homologous chromosomes including arms 1, 2, and 3. Mitotic chromosomes are shown below. (*Upper*) Quadrivalent present in metaphase I. (*c*) Metaphase I configuration, including multivalents of five (*Upper*) and seven chromosomes (*Lower*), of a hypothetical hybrid between the 32N and 32B chromosomal forms of *R. tumida* (21). Not shown are 10 bivalents, including the sex chromosomes.

FIG. 2. Hypothetical speciation event in which acrocentric chromosomes 1, 2, and 3 are fused in different combinations in separate geographically isolated populations. The production of trivalents in animals heterozygous for a single fusion, such as hybrids between the ancestral and derived populations and in the heterozygous founders of the derived populations, fails to result in sterility. However, hybrids between the derived populations are sterile because of quadrivalent formation, and thus they represent reproductively isolated species. The disappearance of populations with the ancestral karyotype, as in the case in *Rhogeessa* (21), removes any chance for gene flow between the species.

each population encountering minimal meiotic problems. Nevertheless, if these two populations hybridize, when combined in a heterozygote the same centric fusions that became fixed with minimal meiotic problems produce reproductive isolation through a greater level of meiotic impairment. All aspects of this model are developed from a synthesis of empirical studies on mammals, and the model appears to be applicable to a diversity of mammalian taxa.

As outlined in Fig. 2, the model relies on the establishment in separate founder populations of different biarmed chromosomes with monobrachial homology (2). Monobrachially homologous biarmed chromosomes result from the independent fusion of homologous acrocentric chromosomes to different nonhomologous acrocentrics (Fig. 2). The resulting biarmed chromosomes have only one arm that is homologous. In meiosis of individuals heterozygous for monobrachially homologous biarmed chromosomes, quadrivalents or more complex multivalents are formed that usually do not segregate normally and result in severely reduced fertility (Fig. 1*b*). On the other hand, heterozygotes for a simple centric fusion form trivalents in meiosis (Fig. 1*a*) that often segregate normally and produce minimal meiotic problems.

The criticisms (refs. 18–20; see Introduction) derived from population genetics theory that normally cast doubt on the probability of chromosomally mediated speciation are not relevant to speciation by fixation of monobrachially homologous chromosomes. This is because the fixation of metacentric chromosomes initially results in only a low level of sterility (Fig. 1*a*), while providing essentially complete reproductive isolation between different derived populations because interpopulational hybrids have a high degree of sterility (Fig. 1*b*).

It is not critical to our model whether selection or stochastic processes drive the centric fusions to fixation within a population, although this is often a most important issue in other models (4, 22). It is only critical that centric fusions commonly become fixed under natural conditions.

EMPIRICAL DATA

Empirical studies on various mammalian taxa document that the frequency of centric fusions for a given taxon range from zero to many. Critical to the model is the fact that centric fusions are often the most common type of rearrangement for certain mammalian taxa. For example, in a G- and C-band analysis of 78 species of bats, centric fusions were more than twice as common as all other types of identifiable rearrangements (23). Capanna *et al.* (24) indicated that individuals of *Mus musculus* heterozygous for a centric fusion have a fertility impaired at the order of 5–18%. Even in individuals of *Mus* that were heterozygous for three centric fusions, <25% of the gametes were aneuploid [had either too many or too few chromosomal arms (25)]. Heterozygotes for centric fusion that have occurred spontaneously in laboratory stocks of mice produced few imbalanced gametes (26), and the mice did not appear to suffer reduction in fitness relative to chromosomal homozygotes (27). Empirical evidence suggests centric fusions are tolerated well in natural populations because they are found as populational polymorphisms in a wide variety of mammalian species (28–31). Indeed, in a sample of 10 rice rats (genus *Oryzomys*) from a natural population, two were homozygous with no fusions, two were heterozygous for one, two were heterozygous for two, one was heterozygous for three and four each, and two were heterozygous for five fusions. A total of nine different fusions were polymorphic in the sample (31).

In contrast to the low level of meiotic problems associated with heterozygosity for centric fusion, heterozygotes for a single monobrachial fusion can develop a much greater impairment of meiosis during gamete production (Fig. 1*b*). Gropp *et al.* (32) demonstrated 58% aneuploidy in a male heterozygous for a monobrachial fusion. This clearly is in

A page from "Speciation by monobrachial centric fusions," Baker and Bickham, 1986.

Drs. Clyde Jones and J. Knox Jones, Jr., with colleagues, used their expertise and the collections of the NSRL and other natural history museums to develop several geographic representations for mammals in the southern and central United States that are considered classics on the topics of mammalian distribution and natural history.

Jones, J. Knox, Jr. 1983. Mammals of the northern Great Plains. University of Nebraska Press, Lincoln. 380 pp.

Jones, J. K., Jr., D. M. Armstrong, and J. R. Choate. 1985. Guide to mammals of the Plains States. University of Nebraska Press, Lincoln. 371 pp.

Jones, J. Knox, Jr., and E. C. Birney. 1988. Handbook of mammals of the north-central states. University of Minnesota Press, Minneapolis. 346 pp.

Choate, J. R., J. K. Jones, Jr., and C. Jones. 1994. Handbook of mammals of the south-central states. Louisiana State University Press, Baton Rouge. 336 pp.

The papers of Dr. Hugh Genoways, the first Curator of Mammalogy at the Museum, on the bat fauna of the Lesser Antilles and other islands of the Caribbean region are regarded as the seminal works on Chiroptera in the Caribbean. At least 17 papers by Genoways and colleagues on bats of the region have been published in the *Occasional Papers* and *Special Publications* series, along with additional articles published in other outlets. A selection of the NSRL publications include:

Baker, R. J., H. H. Genoways, and J. C. Patton. 1978. Bats of Guadeloupe. Occasional Papers, Museum of Texas Tech University 50:1-16.

Carter, C. H. H. H. Genoways, R. S. Loregnard, and R. J. Baker. 1981. Observations on bats from Trinidad, with a checklist of species occurring on that island. Occasional Papers, Museum of Texas Tech University 72:1-27.

Genoways, H. H., R. J. Baker, J. W. Bickham, and C. J. Phillips. 2005. Bats of Jamaica. Special Publications, Museum of Texas Tech University 48:1-154.

Genoways, H. H., R. M. Timm, R. J. Baker, C. J. Phillips, and D. A. Schlitter. 2001. Bats of the West Indian island of Dominica: natural history, aerography, and trophic structure. Special Publications, Museum of Texas Tech University 43:1-43.

Genoways, H. H., S. C. Pedersen, C. J. Phillips, and L. K. Gordon. 2007. Bats of Anguilla, Northern Lesser Antilles. Occasional Papers, Museum of Texas Tech University 270:1-12.

Kwiecinski, G. G., S. C. Pedersen, H. H. Genoways, P. A. Larsen, R. J. Larsen, J. D. Hoffman, F. Springer, C. J. Phillips, and R. J. Baker. 2018. Bats of Saint Vincent, Lesser Antilles. Special Publications, Museum of Texas Tech University 68:1-68.

Pedersen, S. C., G. G. Kwiecinski, H. H. Genoways, R. J. Larsen, P. A. Larsen, C. J. Phillips, and R. J. Baker. 2018. Bats of Saint Lucia, Lesser Antilles. Special Publications, Museum of Texas Tech University 69:1-61.

Pedersen, S. C., H. H. Genoways, M. N. Morton, V. J. Swier, P. A. Larsen, K. C. Lindsay, R. A. Adams, and J. D. Appino. 2006. Bats of Antigua. Occasional Papers, Museum of Texas Tech University 249:1-18.

Pedersen, S. C., P. A. Larsen, H. H. Genoways, M. N. Morton, K. C. Lindsay, and J. Cindric. 2007. Bats of Barbuda, Northern Lesser Antilles. Occasional Papers, Museum of Texas Tech University 271:1-19.

Pedersen, S. C., P. A. Larsen, S. A. Westra, E. van Norren, W. Overman, G. G. Kwiecinski, and H. H. Genoways. 2018. Bats of Sint Eustatius, Caribbean Netherlands. Occasional Papers, Museum of Texas Tech University 353:1-24

A selection of publications by Dr. Hugh H. Genoways and colleagues regarding the bats of the Caribbean region.

The *Occasional Papers* and *Special Publications* series of the NSRL, discussed further below, are known for their publication of faunal checklists, authored primarily by NSRL-affiliated curators, faculty, staff, and students. These include: "Checklist of North American mammals north of Mexico," first published in 1973 and updated in 1975, 1979, 1982, 1986, 1992, 1997, 2003, and 2014; "Annotated checklist of Recent land mammals of Texas" (1988, 1998, 2008); "Annotated checklist of mammals of the Yucatan Peninsula, Mexico" (in four parts; 1973, 1974, 1975); and at least 11 other faunal checklists of mammals of various taxonomic groups and geographic regions. Such checklists are invaluable resources for mammalogists, but in

particular for wildlife management agencies when making land use and conservation decisions.

Although the majority of the 2,000+ publications authored by NSRL curators, staff, and students have been on mammalian topics, the curators and staff of the Invertebrate Zoology Collection also have published numerous papers based on NSRL specimens. James C. Cokendolpher, former Research Scientist and Assistant Curator of Invertebrate Zoology, is a world authority on two orders of arachnids and he has published more than 200 scientific and semi-popular papers and books on a variety of arthropods, protozoa, vertebrates, and plants. His primary interests are in arachnid taxonomy, biodiversity of the Llano Estacado, and natural history museum collections, and many of his papers were based on specimens in the NSRL collection. Dr. Jennifer Girón has been affiliated with the NSRL for only a short time, but to date she has coauthored three publications utilizing NSRL specimens:

Manthey, J. D., J. C. Girón, and J. P. Hruska. 2022. Impact of host demography and evolutionary history on endosymbiont molecular evolution: A test in carpenter ants (genus *Camponotus*) and their *Blochmannia* endosymbionts. Ecology and Evolution, 12, e9026. https://doi.org/10.1002/ece3.9026.

McDonald, P. J., J. A. Parlos, J. C. Cokendolpher, S. J. Robertson, J. K. Krejca, J. C. Girón, R. J. Baker, C. D. Phillips. 2022. Mitochondrial perspective on species identification and delimitation for troglobitic *Cicurina* (Arachnida: Araneae: Hahniidae) from Central Texas. Occasional Papers, Museum of Texas Tech University 381: 1–18.

Girón, J. C., and M. L. Chamorro. 2020. Variability and distribution of the golden-headed weevil *Compsus auricephalus* (Say) (Curculionidae: Entiminae: Eustylini). Biodiversity Data Journal, 8, e55474. https://doi.org/10.3897/BDJ.8.e55474.

Since 1972, **NSRL curators and their students have authored numerous descriptions of new mammal and invertebrate taxa** (species, subspecies, genera, and families) based on specimens archived in the NSRL and other natural history museums. These discoveries expand our understanding of biodiversity and have implications for conserving our wildlife diversity, understanding the impacts of climate change, preventing zoonotic disease transmission, and more.

A selection of publications on invertebrate topics, authored by James C. Cokendolpher and colleagues.

The number of taxa described by a selection of NSRL curators during the last 50 years is summarized below.

Mammals:
Robert L. Packard – 2 species, 7 subspecies
Robert J. Baker – 15 species, 3 subspecies, 2 subgenera, 1 genus, 4 subtribes, 2 tribes, 2 subfamilies
Hugh H. Genoways – 9 species, 11 subspecies
J. Knox Jones, Jr. – 5 species, 28 subspecies
Clyde Jones – 1 species, 1 subspecies
Robert D. Bradley – 7 species, 1 subspecies
David J. Schmidly – 4 species, 1 subspecies

Invertebrates:
James C. Cokendolpher – 93 species, 27 genera, 1 family
Hugh H. Genoways – 1 species

Several NSRL curators and TTU faculty research associates have been active in the study of various zoonotic pathogens as well as wildlife diseases. A selection of important papers on those topics include:

Abbott, K. D., M. L. Milazzo, J. Keith, R. D. Bradley, and C. F. Fulhorst. 2004. Epizootiology of arenaviral infections in the white-throated woodrat (Muridae: Sigmodontinae) and other woodrats in Arizona. Journal of Vector Ecology 29:355-364.

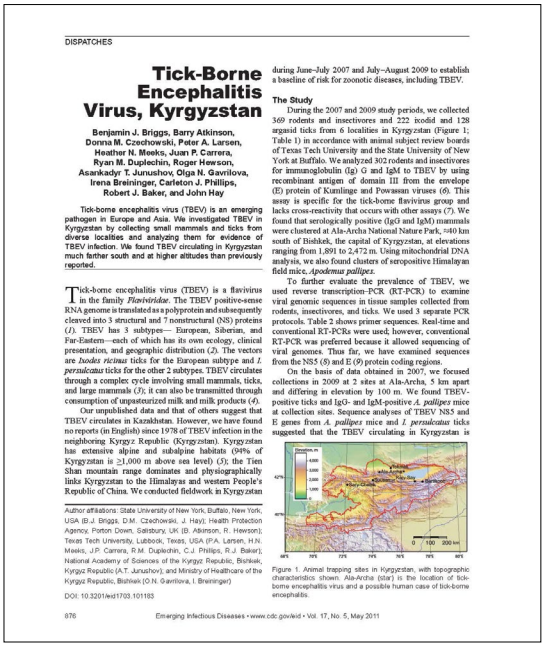
Ayers, S. B., and R. D. Bradley. 2011. Genetic diversity in the transferrin receptor 1 (TfR1) among natural

hosts of the North American arenaviruses. Occasional Papers, Museum of Texas Tech University 304:1-15.

Banerjee, C., L. J. S. Allen, and J. Salazar-Bravo. 2008. Models for an Arenavirus infection in a rodent population: consequences of horizontal, vertical and sexual transmission. Mathematical Biosciences and Engineering 5(4):617-645.

Bohn, S. J., J. M. Turner, L. Warnecke, C. Mayo, L. P. McGuire, V. Misra, T. K. Bollinger, and C. K. R. Willis. 2016. Evidence of 'sickness behaviour' in bats with white-nose syndrome. Behaviour 153(8):981-1003.

Briggs, B. J., B. Atkinson, D. M. Czechowski, P. A. Larsen, H. N. Meeks, J. P. Carrera, R. M. Duplechin, R. Hewson, A. T. Junushov, O. N. Gavrilova, I. Breininger, C. J. Phillips, R. J. Baker, and J. Hay. 2011. Tick-borne encephalitis virus, Kyrgyzstan. Emerging Infectious Diseases 17:876-879.



DISPATCHES

Tick-Borne Encephalitis Virus, Kyrgyzstan

Benjamin J. Briggs, Barry Atkinson, Donna M. Czechowski, Peter A. Larsen, Heather N. Meeks, Juan P. Carrera, Ryan M. Duplechin, Roger Hewson, Asankadyr T. Junushov, Olga N. Gavrilova, Irena Breininger, Carleton J. Phillips, Robert J. Baker, and John Hay

Tick-borne encephalitis virus (TBEV) is an emerging pathogen in Europe and Asia. We investigated TBEV in Kyrgyzstan by collecting small mammals and ticks from diverse localities and analyzing them for evidence of TBEV infection. We found TBEV circulating in Kyrgyzstan much farther south and at higher altitudes than previously reported.

Tick-borne encephalitis virus (TBEV) is a flavivirus in the family *Flaviviridae*. The TBEV positive-sense RNA genome is translated as a polyprotein and subsequently cleaved into 3 structural and 7 nonstructural (NS) proteins (*1*). TBEV has 3 subtypes— European, Siberian, and Far-Eastern—each of which has its own ecology, clinical presentation, and geographic distribution (*2*). The vectors are *Ixodes ricinus* ticks for the European subtype and *I. persulcatus* ticks for the other 2 subtypes. TBEV circulates through a complex cycle involving small mammals, ticks, and large mammals (*3*); it can also be transmitted through consumption of unpasteurized milk and milk products (*4*).

Our unpublished data and that of others suggest that TBEV circulates in Kazakhstan. However, we have found no reports (in English) since 1978 of TBEV infection in the neighboring Kyrgyz Republic (Kyrgyzstan). Kyrgyzstan has extensive alpine and subalpine habitats (94% of Kyrgyzstan is ≥1,000 m above sea level) (*5*); the Tien Shan mountain range dominates and physiographically links Kyrgyzstan to the Himalayas and western People's Republic of China. We conducted fieldwork in Kyrgyzstan during June–July 2007 and July–August 2009 to establish a baseline of risk for zoonotic diseases, including TBEV.

Author affiliations: State University of New York, Buffalo, New York, USA (B.J. Briggs, D.M. Czechowski, J. Hay); Health Protection Agency, Porton Down, Salisbury, UK (B. Atkinson, R. Hewson); Texas Tech University, Lubbock, Texas, USA (P.A. Larsen, H.N. Meeks, J.P. Carrera, R.M. Duplechin, C.J. Phillips, R.J. Baker); National Academy of Sciences of the Kyrgyz Republic, Bishkek, Kyrgyz Republic (A.T. Junushov); and Ministry of Healthcare of the Kyrgyz Republic, Bishkek (O.N. Gavrilova, I. Breininger)

DOI: 10.3201/eid1703.101183

The Study

During the 2007 and 2009 study periods, we collected 369 rodents and insectivores and 222 Ixodid and 128 argasid ticks from 6 localities in Kyrgyzstan (Figure 1; Table 1) in accordance with animal subject review boards of Texas Tech University and the State University of New York at Buffalo. We analyzed 302 rodents and insectivores for immunoglobulin (Ig) G and IgM to TBEV by using recombinant antigen of domain III from the envelope (E) protein of Kumlinge and Powassan viruses (*6*). This assay is specific for the tick-borne flavivirus group and lacks cross-reactivity that occurs with other assays (*7*). We found that serologically positive (IgG and IgM) mammals were clustered at Ala-Archa National Nature Park, ≈40 km south of Bishkek, the capital of Kyrgyzstan, at elevations ranging from 1,891 to 2,472 m. Using mitochondrial DNA analysis, we also found clusters of seropositive Himalayan field mice, *Apodemus pallipes*.

To further evaluate the prevalence of TBEV, we used reverse transcription–PCR (RT-PCR) to examine viral genomic sequences in tissue samples collected from rodents, insectivores, and ticks. We used 3 separate PCR protocols. Table 2 shows primer sequences. Real-time and conventional RT-PCRs were used; however, conventional RT-PCR was preferred because it allowed sequencing of viral genomes. Thus far, we have examined sequences from the NS5 (*8*) and E (*9*) protein coding regions.

On the basis of data obtained in 2007, we focused collections in 2009 at 2 sites at Ala-Archa, 5 km apart and differing in elevation by 100 m. We found TBEV-positive ticks and IgG- and IgM-positive *A. pallipes* mice at collection sites. Sequence analyses of TBEV NS5 and E genes from *A. pallipes* mice and *I. persulcatus* ticks suggested that the TBEV circulating in Kyrgyzstan is

Figure 1. Animal trapping sites in Kyrgyzstan, with topographic characteristics shown. Ala-Archa (star) is the location of tick-borne encephalitis virus and a possible human case of tick-borne encephalitis.

Buchholz, M. J., E. A. Wright, B. A. Grisham, R. D. Bradley, T. L. Arsuffi, and W. C. Conway. 2021. Characterization of the prion protein gene in axis deer (*Axis axis*) and implications for susceptibility to chronic wasting disease. Prion 15:44-52.

Cajimat, M. N. B., M. L. Milazzo, J. N. Borchert, K. D. Abbott, R. D. Bradley, and C. F. Fulhorst. 2008. Diversity among Tacaribe serocomplex viruses (family Arenaviridae) naturally associated with the Mexican woodrat (*Neotoma mexicana*). Virus Research 133:211-217.

Cajimat, M. N. B., M. L. Milazzo, M. R. Mauldin, R. D. Bradley, and C. F. Fulhorst. 2013. Diversity among Tacaribe viruses (Family Arenaviridae) associated with the southern plains woodrat (*Neotoma micropus*). Virus Research 178:486-494.

Cajimat, M. N. B., M. L. Milazzo, R. D. Bradley, and C. F. Fulhorst. 2007. Catarina virus, an arenaviral species principally associated with *Neotoma micropus* (Southern Plains Woodrat) in Texas. American Journal of Tropical Medicine and Hygiene 77:732-736.

Cajimat, M. N. B., M. L. Milazzo, R. D. Bradley, and C. F. Fulhorst. 2012. Ocozocoautla de Espinos virus, agent of hemorrhagic fever in southern Mexico? Journal of Emerging Infectious Diseases 18:401-405.

Cajimat, M. N. B., M. L. Milazzo, M. L. Haynie, J. D. Hanson, R. D. Bradley, and C. F. Fulhorst. 2011. Diversity and phylogenetic relationships among the North American Tacaribe serocomplex viruses (Family Arenaviridae). Virology 421:87-95.

Calderon, A., C. Guzman, J. Salazar-Bravo, T. Figueiredo, S. Mattar, and G. Arrieta. 2016. Viral zoonoses that fly with bats: a review. 2016. MANTER: Journal of Parasite Biodiversity (ISSN 2470-8224), Occasional Papers 6, September 30, 2016. http://doi.org/10.13014/K2BG2KWF.

Cheng T., H. Mayberry, L. P. McGuire, J. Hoyt, K. Langwig, H. Nguyen, K. Parise, J. Foster, C. K. R. Willis, A. M. Kilpatrick, and W. F. Frick. 2016. Efficacy of a probiotic bacterium to treat bats affected by the disease white-nose syndrome. Journal of Applied Ecology. dx.doi.org/10.1111/1365-2664.12757.

Chu, Y.-K., et al. 2006. Phylogenetic and geographical relationships of hantavirus strains in eastern and western Paraguay. American Journal of Tropical Medicine and Hygiene 75:1127-1134.

Chu, Y-K., R. D. Owen, L. González, and C. B. Jonsson. 2003. The complex ecology of hantavirus in Paraguay. American Journal of Tropical Medicine and Hygiene 69:263-268.

Chu, Y-K., R.D. Owen, C. Sánchez-Hernández, Ma. de L. Romero-Almaraz, and C.B. Jonsson. 2008. Genetic characterization and phylogeny of a hantavirus from Western Mexico. Virus Research 131:180-188.

Coffey, L. L., A.-S. Carrara, S. Paessler, R. D. Bradley, M. L. Haynie, R. B. Tesh, and S. C. Weaver. 2004. Experimental infection of cotton rats (*Sigmodon hispidus*) from endemic and non-endemic areas with everglades virus. Emerging Infectious Diseases 10:2182-2188.

Cook, J. A., et al. 2016. Transformational principles for NEON sampling of mammalian parasites and pathogens: a response to Springer and Colleagues. BioScience 66:917-919.

Fulhorst, C. F., M. L. Milazzo, D. S. Carroll, R. N. Charrel, and R. D. Bradley. 2002. Natural host relationships and genetic diversity of Whitewater Arroyo virus in southern Texas. American Journal of Tropical Medicine and Hygiene 67:114-118.

Fulhorst, C. F., M. L. Milazzo, R. D. Bradley, and L. L. Peppers. 2001. Experimental infection of *Neotoma albigula* (Muridae) with Whitewater Arroyo virus (Arenaviridae). American Journal of Tropical Medicine and Hygiene 65:147-151.

Fulhorst, C. F., R. N. Charrel, S. C. Weaver, T. G. Ksiazek, R. D. Bradley, M. L. Milazzo, R. B. Tesh, and M. D. Bowen. 2001. Geographic distribution and genetic diversity of Whitewater Arroyo virus in the southwestern United States. Journal of Emerging Infectious Diseases 7:403-407.

Fulhorst, C. F., S. G. Bennett, M. L. Milazzo, H. Murray, Jr., J. P. Webb, Jr., M. N. B. Cajimat, and R. D. Bradley. 2002. Bear Canyon virus: an arenavirus naturally associated with the California mouse (*Peromyscus californicus*). Journal of Emerging Infectious Diseases 8:717-721.

González-Ittig, R., J. Salazar-Bravo, J. J. Polop, and C. N. Gardenal. 2008. Isolation and characterization of microsatellite markers in *Oligoryzomys longicaudatus* (Muridae, Sigmodontinae, Oryzomini), the natural reservoir of genotype Andes Hantavirus. Molecular Ecology Resources 8:1466-1468.

Goodin, D. G., D. E. Koch, R. Owen, Y. K. Chu, J. M. S. Hutchinson, and C. B. Jonsson. 2006. Land cover associated with hantavirus presence in Paraguay. Global Ecology and Biogeography 15:519-527.

Goodin, D., R. Paige, R. D. Owen, K. Ghimire, D. E. Koch, Y.-K. Chu, and C. B. Jonsson. 2009. Microhabitat characteristics of *Akodon montensis*, a reservoir for hantavirus, and hantaviral seroprevalence in an Atlantic forest site in eastern Paraguay. Journal of Vector Ecology 34:104-113.

Guzman, C., S. Mattar, S. Levis, N. Pini,, L. T. Figuereido, J. Mills and J. Salazar-Bravo. 2013. Prevalence of antibodies to hantaviruses in humans and rodents in the Caribbean region of Colombia determined using Araraquara and Maciel virus antigens. Memorias do Instituto Oswaldo Cruz 108:167-171.

Haynie, M. L., K. D. Abbott, C. F. Fulhorst, and R. D. Bradley. 2016. Assessment of genetic diversity within populations of *Neotoma albigula* (White-throated Woodrats) naturally associated with Tacaribe Serocomplex viruses (Family Arenaviridae). Occasional Papers, Museum of Texas Tech University 344:1-26.

Holsomback, T., C. Van Nice, R. C., N. McIntyre, A. Abuzeineh, and J. Salazar-Bravo. 2013. Socioecology of the marsh rice rat (*Oryzomys palustris*) and the spatiotemporal distribution of Bayou virus (BAYV) in Coastal Texas. Geospatial Health 7:289-298

Holsomback, T., N. McIntyre, R. Nisbett, R. Strauss, Y.-K. Chu, A. Abuzeineh, N. de la Sancha, C. Dick, C. Jonsson, and B. Morris. 2009. Bayou virus detected in non-oryzomyine rodent hosts: an assessment of habitat composition, reservoir community structure, and marsh rice rat social dynamics. Journal of Vector Ecology 34: 9-21.

Kading, R., and T. Kingston. 2020. Common ground: the foundation of interdisciplinary research on bat disease emergence. PLOS Biology 18(11): e3000947.

Mantooth, S. J., M. L. Milazzo, R. D. Bradley, C. L. Hice, G. Ceballos, R. B. Tesh, and C. F. Fulhorst. 2001. Geographical distribution of rodent-associated hantaviruses in Texas. Journal of Vector Ecology 26:7-14.

Mayberry, H. W., L. P. McGuire, and C. K. R. Willis. 2018. Hibernating little brown bats exhibit pronounced behavioural activity at torpid body temperatures: implications for hibernation energetics and white-nose syndrome. Journal of Comparative Physiology B 188:333–343.

McGuire, L. P., H. W. Mayberry, Q. E. Fletcher, and C. K. R. Willis. 2019. An experimental test of energy and electrolyte supplementation as a mitigation strategy for white-nose syndrome. Conservation Physiology 7. DOI: 10.1093/conphys/coz006.

McIntyre, N., et al. 2005. A longitudinal study of Bayou virus, hosts, and habitat. American Journal of Tropical Medicine and Hygiene 73:1043-1049.

McIntyre, N., R. Nisbett, A. Abuzeineh, T. Holsomback, Y.-K. Chu, J. Carmichael, N. De La Sancha, C. Dick, C. Jonsson, and R. Owen. 2009. Ecological correlates of serological status for Bayou virus in *Oryzomys palustris* (Rodentia: Sigmodontinae). Mastozoologia Neotropical 16: 83-93.

Milazzo, M. L., A. Barragán-Gomez, J. D. Hanson, J. G. Estrada-Franco, E. Arellano, F. X. González-Cózatl, I. Fernández-Salas, F. Ramirez-Aguilar, D. S. Rogers, R. D. Bradley, and C. F. Fulhorst. 2010. Antibodies to Tacaribe serocomplex viruses (Family Arenaviridae, genus *Arenavirus*) in cricetid rodents from New Mexico, Texas, and Mexico. Vector-Borne and Zoonotic Diseases 10:629-637.

Milazzo, M. L., B. R. Amman, M. N. B. Cajimat, F. M. Méndez-Harclerode, J. R. Suchecki, J. D. Hanson, M. L. Haynie, B. D. Baxter, C. Milazzo, Jr., S. A. Carroll, D. S. Carroll, D. C. Ruthven, III, R. D. Bradley, and C. F. Fulhorst. 2013. Ecology of Catarina Virus (family Arenaviridae) in Southern Texas, 2001-2004. Vector-Borne and Zoonotic Diseases 13:50-59.

Milazzo, M. L., M. N. B. Cajimat, H. E. Romo, J. G. Estrada-Franco, L. I. Iñiguez-Dávalos, R. D. Bradley, and C. F. Fulhorst. 2012. Geographic distribution of hantaviruses associated with Neotomine and Sigmodontine rodents in Mexico. Journal of Emerging Infectious Diseases 18:571-576.

Milazzo, M. L., M. N. B. Cajimat, J. D. Hanson, R. D. Bradley, M. Quintana, C. Sherman, R. T. Velasquez, and C. F. Fulhorst. 2006. Catacamas virus, a hantaviral species naturally associated with *Oryzomys couesi* (Coues' Oryzomys) in Honduras. American Journal of Tropical Medicine and Hygiene 75:1003-1010.

Milazzo, M. L., M. N. B. Cajimat, M. H. Richter, R. D. Bradley, and C. F. Fulhorst. 2017. Muleshoe virus and other hantaviruses associated with Neotomine or Sigmodontine rodents in Texas. The Journal of Vector-Borne and Zoonotic Diseases 17:720-729.

Milazzo, M. L., M. N. B. Cajimat, M. L. Haynie, K. D. Abbott, R. D. Bradley, and D. F. Fulhorst. 2008. Diversity among Tacaribe serocomplex viruses (family Arenaviridae) naturally associated with the white-throated woodrat (*Neotoma albigula*) in the southwestern United States. Vector-borne and Zoonotic Diseases 8:523-450.

Milazzo, M. L., M. N. Cajimat, M. R. Mauldin, S. G. Bennett, B. D. Hess, M. P. Rood, C. A. Conlan, K. Nguyen, J. W. Wekesa, R. D. Ramos, R. D. Bradley, and C. F. Fulhorst. 2015. Epizootiology of Tacaribe serocomplex viruses (Arenaviridae) associated with neotomine rodents (Cricetidae, Neotominae) in southern California. Vector-Borne and Zoonotic Diseases 15:156-166.

Olival, K. J., et al. Possibility for reverse zoonotic transmission of SARS-CoV-2 to free-ranging wildlife: a case study of bats. Plos Pathogens. https://doi.org/10.1371/journal.ppat.1008758.

Phillips, C. J., A. M. Harrington, T. L. Yates, G. L. Simpson, and R. J. Baker. 2009. Global disease surveillance, emergent disease preparedness, and national security. Museum of Texas Tech University, Lubbock. iv+83 pp.

Pinto, C. M., B. D Baxter, J. D. Hanson, F. M. Méndez-Harclerode, J. R. Suchecki, M. J. Grijalva, C. F. Fulhorst, and R. D. Bradley. 2010. Using museum collections to detect pathogens: *Trypanosoma cruzi* in Texas woodrats. Journal of Emerging Infectious Diseases 16:356-357.

Radoshitzky, S., J. Kuhn, C. Spiropoulou, C. Albarino, D. Nguyen, J. Salazar-Bravo, T. Dorfman, A. Lee, A. Wang, S. Ross, H. Choe, and M. Farzan. 2008. Receptor determinants of zoonotic transmission of New World Hemorrhagic Fever arenaviruses. Proceedings of the National Academy of Sciences of the USA 105:2664-2669.

PRION
2021, VOL. 15, NO. 1, 44–52
https://doi.org/10.1080/19336896.2021.1910177

Taylor & Francis
Taylor & Francis Group

SHORT COMMUNICATIONS

OPEN ACCESS Check for updates

Characterization of the prion protein gene in axis deer (*Axis axis*) and implications for susceptibility to chronic wasting disease

Matthew J. Buchholz[a], Emily A. Wright[b], Blake A. Grisham[a], Robert D. Bradley[b,c], Thomas L. Arsuffi[d], and Warren C. Conway[a]

[a]Department of Natural Resources Management, Texas Tech University,Lubbock, TX USA; [b]Department of Biological Sciences, Texas Tech University, Lubbock, TX USA; [c]Natural Science Research Laboratory, Museum of Texas Tech University, Lubbock, TX USA; [d]Llano River Field Station, Texas Tech University, Junction, TX USA

ABSTRACT

Axis deer (*Axis axis*) occur both in captivity and free-ranging populations in portions of North America, but to-date, no data exist pertaining to the species' susceptibility to CWD. We sequenced the prion protein gene (*PRNP*) from axis deer. We then compared axis deer PrP^{C} sequences and amino acid polymorphisms to those of CWD susceptible species. A single *PRNP* allele with no evidence of intraspecies variation was identified in axis deer that indicates axis deer *PRNP* is most similar to North American elk (*Cervus canadensis*) *PRNP*. Therefore, axis deer may be susceptible to CWD. We recommend proactively increasing CWD surveillance for axis deer, particularly where CWD has been detected and axis deer are sympatric with native North American CWD susceptible species.

ARTICLE HISTORY
Received 15 January 2021
Revised 12 March 2021
Accepted 24 March 2021

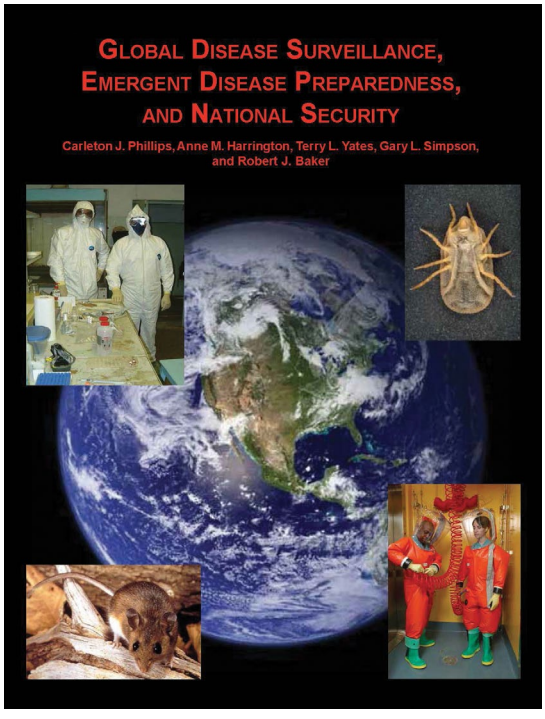
KEYWORDS
Axis axis; axis deer; chital; chronic wasting disease; prion protein; *prnp*; ppp

Introduction

Chronic wasting disease (CWD) is a fatal, transmissible spongiform encephalopathy (TSE) of cervids that belongs to the greater classification of TSE/prion diseases [e.g. bovine spongiform encephalopathy in cattle (*Bos taurus*), scrapie in sheep (*Ovis aries*) and goats (*Capra hircus*), feline spongiform encephalopathy in felids, and Creutzfeldt-Jakob disease in humans (*Homo sapiens*)], which is caused by the aggregation of a misfolded isoform (PrP^{CWD}) of the cellular prion protein (PrP^{C}) [1,2]. The cellular prion protein is encoded for in its entirety by the third exon of the prion protein gene (*PRNP*) [1]. Chronic wasting disease was first documented in captive mule deer (*Odocoileus hemionus*) in Colorado in the 1960s [2], and has since been detected in free-ranging and captive cervid populations in 26 US states and 3 Canadian provinces, as well as internationally in Finland, Norway, Sweden, and South Korea [3–6]. Cases of CWD have been detected in other native North American species, including white-tailed deer (*Odocoileus virginianus*), North American elk (*Cervus canadensis*), and moose (*Alces alces*), as well as species that are not native, but have been introduced, to North America including reindeer (*Rangifer tarandus*), sika deer (*C. nippon*), red deer (*C. elaphus*), Reeve's muntjac (*Muntiacus reevesi*), and fallow deer (*Dama dama*) [3–8]. The expanding distribution, movement of, and increasing number of, known susceptible species is a concern for wildlife stakeholders worldwide, and efforts to limit the spread of CWD are extensive.

Many studies have focused upon assessing CWD susceptibility in cervids by sequencing *PRNP* and identifying amino acid substitutions in PrP^{C}. For example, amino acid substitutions such as Q95H, G96S, A116G, and Q226K in white-tailed deer, S225F in mule deer, and M132L in elk are linked to reduced CWD prevalence and prolonged incubation periods/life expectancy post–CWD infection within the proportion of those species with those substitutions [1,9–11]. The potential for interspecific transmission of CWD between individuals of different cervid species with different *PRNP* genotypes and PrP^{C} variants is documented in mouse models, and data suggests CWD susceptibility is not limited to species within Cervidae [12–15]. Phylogenetic analyses and challenge studies indicate species beyond Cervidae, including pronghorn (*Antilocapra americana*), bighorn sheep (*Ovis canadensis*), mountain goat (*Oreamnos americanus*), and squirrel monkeys (*Saimiri sciureus*) may be susceptible to

CONTACT Matthew J. Buchholz matthew.buchholz@ttu.edu Texas Tech University, Box 42125, Goddard Building, Lubbock, Texas 79409.



Rocha, R., S. A. Aziz, et al. 2021. Bat conservation and zoonotic disease risk: the need for trans-disciplinary and evidence-based solutions to an action plan to prevent misguided persecution in the aftermath of COVID-19. Animal Conservation. DOI: https://doi.org/10.1111/acv.12636.

Ruedas, L, J. Salazar–Bravo, D. Tinnin, B. Armien, L. Cáceres, A. García, M. Avila, F. Gracia, G. Suzan, C. J. Peters, T.L. Yates, and J. N. Mills. 2004. Community ecology of small mammal populations in Panamá following an outbreak of Hantavirus Pulmonary Syndrome. Journal of Vector Ecology 29:177-191.

Sabino-Santos, G., Jr, F. G. M. Maia, C. B. Jonsson, D. G. Goodin, J. Salazar-Bravo, and L. T. M. Figueiredo. 2016. Serologic evidence of mammarenaviruses among wild rodents in Brazil. Journal of Wildlife Diseases. DOI: http://dx.doi.org/10.7589/2015-09-252

Sabino-Santos, Jr., et al. 2018. Natural infection of Neotropical bats with hantavirus in Brazil. Scientific Reports 8, article number: 9018.

Sabino-Santos, Jr., G., F. G. Motta Maia, T. M. Vieira, R. d. L. Muylaert, S. M. Lima, C. B. Gonçalves, P. D. Barroso, M. N. Melo, C. B. Jonsson, D. Goodin, J. Salazar-Bravo, L. T. M. Figueiredo. 2015. Evidence of hantavirus infection among bats in Brazil. American Journal Tropical Medicine and Hygiene 93:404–406.

Salazar-Bravo, J., B. Armién, G. Suzán, A. Armién, L. Ruedas, M. Avila, Y. Zaldívar, J. Pascale, F. Gracia and T. Yates. 2004. Serosurvey of wild rodents for Hantaviruses in Panama, 2000–2002. Journal of Wildlife Diseases 40:103-109.

Salazar-Bravo, J., C. J. Phillips, R. D. Bradley, R. J. Baker, T. L. Yates, and L. A. Ruedas. 2006. Voucher specimens for SARS-linked bats. Letter to the editor of Science. Science 311:1099-1100.

Suzán, G., E. Marcé, J. T. Giermakowski, B. Armién, J. Pascale, J. Mills, G. Ceballos, A. Gómez, A.A. Aguirre, J. Salazar-Bravo, A. Armién, R. Parmenter, and T. Yates. 2008. The effect of habitat fragmentation and species diversity loss on Hantavirus prevalence in Panama. Annals of the New York Academy of Sciences 1149:80-83.

Wilcox, A., L. T. Warnecke, J. M. Turner, L. P. McGuire, J. W. Jameson, V. Misra, T. Bollinger, and C. K. R. Willis. 2014. Behavioural changes of hibernating little brown bats experimentally inoculated with

the pathogen that causes white-nose syndrome. Animal Behaviour 88:157-164.

Yates, T. L., et al. 2002. The ecology and evolutionary history of an emergent disease: Hantavirus Pulmonary Syndrome. Bioscience 52:989-998.

Dr. Caleb D. Phillips and his colleagues are actively using the recently established Wolcott Wound Care Collection of the GRC to conduct research focusing on human biology. Publications resulting from that work include:

Tipton, C. D., R. D. Wolcott, N. E. Sanford, C. Miller, G. Pathak, T. K. Silzer, J. Sun, D. Fleming, K. P. Rumbaugh, T. D. Little, N. Phillips, C. D. Phillips. 2020. Patient genetics is linked to chronic wound microbiome composition and healing. PLoS Pathog 16(6):e1008511. https://doi.org/10.1371/journal.ppat.1008511.

PLOS PATHOGENS

RESEARCH ARTICLE

Patient genetics is linked to chronic wound microbiome composition and healing

Craig D. Tipton[1,2], Randall D. Wolcott[3], Nicholas E. Sanford[4], Clint Miller[3], Gita Pathak[1], Talisa K. Silzer[1], Jie Sun[1], Derek Fleming[3], Kendra P. Rumbaugh[5,6], Todd D. Little[7,8], Nicole Phillips[4], Caleb D. Phillips[1,9]*

1 Department of Biological Sciences, Texas Tech University, Lubbock, Texas, United States of America, 2 RTL Genomics, Lubbock, Texas, United States of America, 3 Southwest Regional Wound Care Center, Lubbock, Texas, United States of America, 4 Microbiology, Immunology & Genetics, University of North Texas Health Science Center, Fort Worth, Texas, United States of America, 5 Department of Surgery, Texas Tech University Health Sciences Center, Lubbock, Texas, United States of America, 6 Burn Center of Excellence, Texas Tech University Health Sciences Center, Lubbock, Texas, United States of America, 7 Department of Educational Psychology, Texas Tech University, Lubbock, Texas, United States of America, 8 Optentia Research Focus Area, North West University, Vanderbijlpark, South Africa, 9 Natural Science Research Laboratory, Texas Tech University, Lubbock, Texas, United States of America

* caleb.phillips@ttu.edu

Abstract

The clinical importance of microbiomes to the chronicity of wounds is widely appreciated, yet little is understood about patient-specific processes shaping wound microbiome composition. Here, a two-cohort microbiome-genome wide association study is presented through which patient genomic loci associated with chronic wound microbiome diversity were identified. Further investigation revealed that alternative *TLN2* and *ZNF521* genotypes explained significant inter-patient variation in relative abundance of two key pathogens, *Pseudomonas aeruginosa* and *Staphylococcus epidermidis*. Wound diversity was lowest in *Pseudomonas aeruginosa* infected wounds, and decreasing wound diversity had a significant negative linear relationship with healing rate. In addition to microbiome characteristics, age, diabetic status, and genetic ancestry all significantly influenced healing. Using structural equation modeling to identify common variance among SNPs, six loci were sufficient to explain 53% of variation in wound microbiome diversity, which was a 10% increase over traditional multiple regression. Focusing on *TLN2*, genotype at *rs803191*6 explained expression differences of alternative transcripts that differ in inclusion of important focal adhesion binding domains. Such differences are hypothesized to relate to wound microbiomes and healing through effects on bacterial exploitation of focal adhesions and/or cellular migration. Related, other associated loci were functionally enriched, often with roles in cytoskeletal dynamics. This study, being the first to identify patient genetic determinants for wound microbiomes and healing, implicates genetic variation determining cellular adhesion phenotypes as important drivers of infection type. The identification of predictive biomarkers for chronic wound microbiomes may serve as risk factors and guide treatment by informing patient-specific tendencies of infection.

OPEN ACCESS

Citation: Tipton CD, Wolcott RD, Sanford NE, Miller C, Pathak G, Silzer TK, et al. (2020) Patient genetics is linked to chronic wound microbiome composition and healing. PLoS Pathog 16(6): e1008511. https://doi.org/10.1371/journal.ppat.1008511

Editor: Matthew C. Wolfgang, University of North Carolina at Chapel Hill, UNITED STATES

Received: August 23, 2019

Accepted: April 1, 2020

Published: June 18, 2020

Data Availability Statement: The scripts used for all statistical analysis are available at https://github.com/genotypes/noGWAS_wounds. Genotype data are available at GEO study GSE149314.

Funding: This work was supported by Texas Tech University Office Research and Innovation. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing interests: The authors have declared that no competing interests exist.

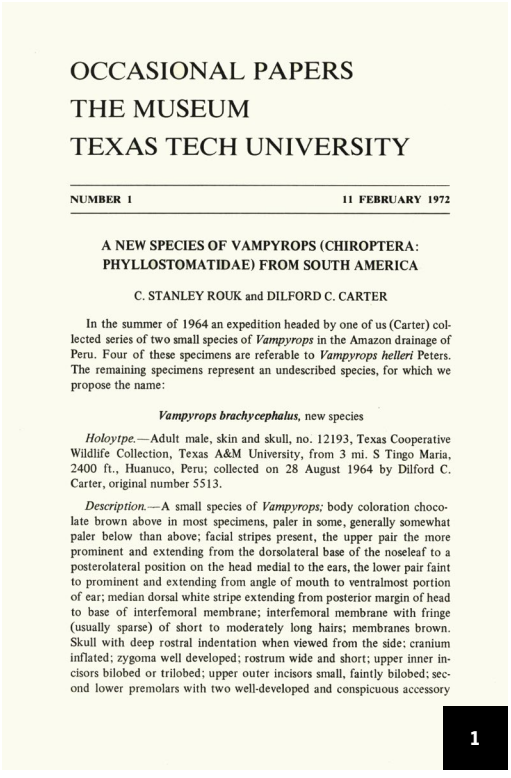
Tipton, C. D., N. E. Sanford, J. A. Everett, R. A. Gabrilska, R. D. Wolcott, K. P. Rambaugh, and C. D. Phillips. 2019. Chronic wound microbiome colonization on mouse model following cryogenic preservation. PLoS ONE 14(8):e0221565. https://doi.org/10.1371/journal.pone.0221565.

Tipton, C. D., M. E. Mathew, R. A. Wolcott, R. D. Wolcott, T. Kingston, and C. D. Phillips. 2017. Temporal dynamics of relative abundances and bacterial succession in chronic wound communities. Wound Repair and Regeneration 25:673-679. https://doi.org/10.1111/wrr.12555.

Additionally, papers authored by NSRL curators and staff on the topics of the value of collections, collections management, and curatorial standards have been of particular significance, and these papers have been recognized by the natural history collections community for their value. These papers are discussed in the section below, Collections Growth and Management.

In addition to the scholarly output of NSRL-based faculty, staff, and students, the NSRL has had a significant impact on the scholarly output of universities and other institutions worldwide as a direct result of loans from the mammal, invertebrate, and GRC collections since the 1970s. Although it is impossible to determine a comprehensive count, **we estimate that researchers at other institutions have authored at least 2,000 papers based upon specimens and tissues archived at the NSRL**.

Since 1972, the NSRL has produced two peer-reviewed publication series, *Occasional Papers of the Museum* (384 volumes, to date) and *Special Publications of the Museum* (76 volumes, to date). These series are well known and respected by authors for being a quality outlet for their publications. The papers published in *Occasional Papers* and *Special Publications* typically are the result of research efforts that utilized specimens and tissues previously or subsequently archived in accredited natural history museums. Relevant topics include taxonomic studies, faunal lists, species descriptions, zoonoses, distributional records, and field and museum techniques and methodology, including molecular methods that are applicable to field or museum research. Submitted manuscripts are peer-reviewed, and authors are required to produce a final manuscript that is suitable for the series, adheres to scientific and academic standards, revised as required, and well written. Authors appreciate the timely review and decision-making process of the Editors, the overall speed of the publication process (3–6 months on average, as opposed to 1–2 years for most journals), and the low cost of the page charges compared to most journals. Further, all volumes of *Occasional Papers* and *Special Publications* are available for free viewing and download from the NSRL website. Printed copies are distributed to more than



OCCASIONAL PAPERS
THE MUSEUM
TEXAS TECH UNIVERSITY

NUMBER 1 — 11 FEBRUARY 1972

A NEW SPECIES OF VAMPYROPS (CHIROPTERA: PHYLLOSTOMATIDAE) FROM SOUTH AMERICA

C. STANLEY ROUK and DILFORD C. CARTER

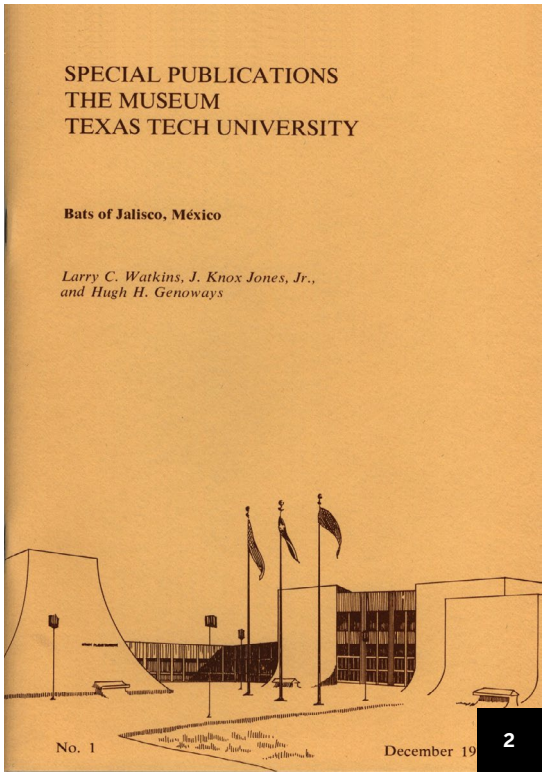
In the summer of 1964 an expedition headed by one of us (Carter) collected series of two small species of *Vampyrops* in the Amazon drainage of Peru. Four of these specimens are referable to *Vampyrops helleri* Peters. The remaining specimens represent an undescribed species, for which we propose the name:

Vampyrops brachycephalus, new species

Holoytpe.—Adult male, skin and skull, no. 12193, Texas Cooperative Wildlife Collection, Texas A&M University, from 3 mi. S Tingo Maria, 2400 ft., Huanuco, Peru; collected on 28 August 1964 by Dilford C. Carter, original number 5513.

Description.—A small species of *Vampyrops;* body coloration chocolate brown above in most specimens, paler in some, generally somewhat paler below than above; facial stripes present, the upper pair the more prominent and extending from the dorsolateral base of the noseleaf to a posterolateral position on the head medial to the ears, the lower pair faint to prominent and extending from angle of mouth to ventralmost portion of ear; median dorsal white stripe extending from posterior margin of head to base of interfemoral membrane; interfemoral membrane with fringe (usually sparse) of short to moderately long hairs; membranes brown. Skull with deep rostral indentation when viewed from the side; cranium inflated; zygoma well developed; rostrum wide and short; upper inner incisors bilobed or trilobed; upper outer incisors small, faintly bilobed; second lower premolars with two well-developed and conspicuous accessory

1



SPECIAL PUBLICATIONS
THE MUSEUM
TEXAS TECH UNIVERSITY

Bats of Jalisco, México

Larry C. Watkins, J. Knox Jones, Jr., and Hugh H. Genoways

No. 1 — December 19

2

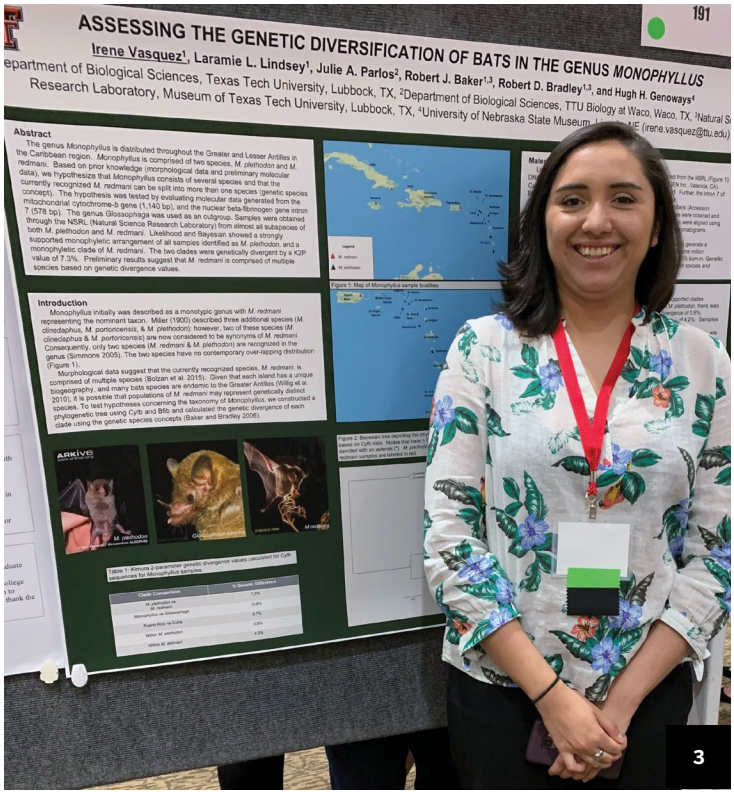
1 & 2. The first two volumes of Occasional Papers and Special Publications, 1972.

3. Irene Vasquez presenting a poster at the Texas Tech University Undergraduate Research Conference.

40 libraries. Lisa Bradley, Senior Research Associate, currently serves as Production Editor for the *Occasional Papers* and *Special Publications* series (see Appendix B: *Current Staff Profiles*).

In addition to the publication of scientific papers, a significant component of scholarly activity is the presentation of research results at regional, state, national, and international meetings of scientific societies. The TTU faculty, staff, and students affiliated with the NRSL present their research at these meetings on a regular basis, and often receive recognition for their presentations with awards. Dr. Bradley's students, alone, have presented more than 375 talks at such meetings since 1997.

Clearly, the scholarly output of the faculty, staff, and students associated with the NSRL throughout its 50-year history has been impressive. **This productivity would not have been possible without the services that the NSRL provides by archiving its vital collections of specimens, genetic resources, and associated data at the highest standards and by making those resources available to Texas Tech researchers and students, as well as the scientific community worldwide.**



3

Collections Growth and Management

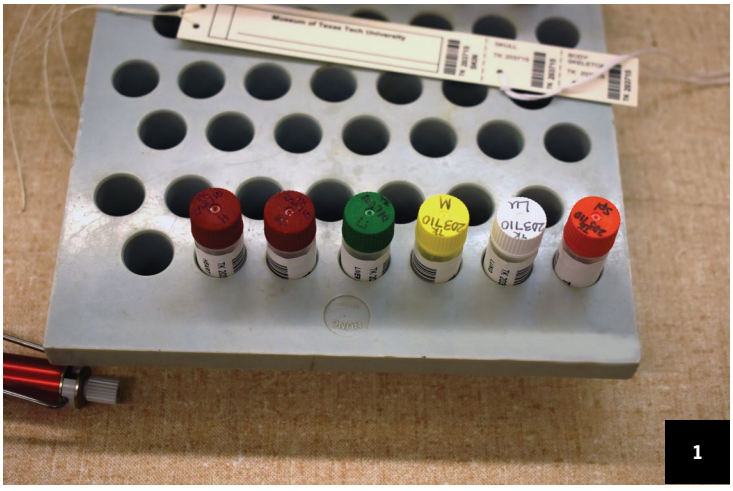
The growth of the collections of the NSRL since its establishment has been impressive. In 50 years, due almost entirely to the active field collecting of NSRL-affiliated faculty and students, the **Mammal Collection grew from a few thousand specimens to more than 156,000 specimens today, making it one of the fastest growing such collections**. The collection reached milestones of 50,000 specimens in 1988; 100,000 in 2003; and 150,000 in 2019. The continued growth of the Mammal Collection results in increased taxonomic, geographic, and temporal diversity within the collection. Thus, **the value of the collection to scientific research continues to grow as the size and diversity of the collection expands**.

The growth rate of the Genetic Resources Collection has been even faster than that of the Mammal Collection, due in part to the increasing number of samples (and types of samples) obtained from individual specimens in response to the needs of researchers.

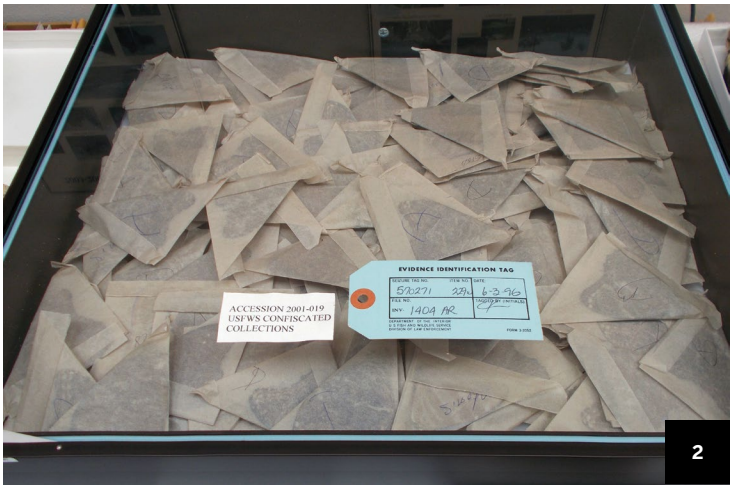
A row of specimen cabinets in the Mammal Collection of the NSRL.

The exact count of samples in the GRC was not well known, historically, but in 1989 it was estimated to contain 25,000 samples from 10,000 specimens. An inventory and reorganization of the collection was conducted from 2003 to 2005, revealing that the collection by that latter date contained more than 220,000 samples from more than 65,000 individuals. Today, **the GRC contains more than 470,000 samples from more than 110,000 individuals of mammals**, in addition to a limited number of samples from other taxonomic groups (birds, invertebrates, herps).

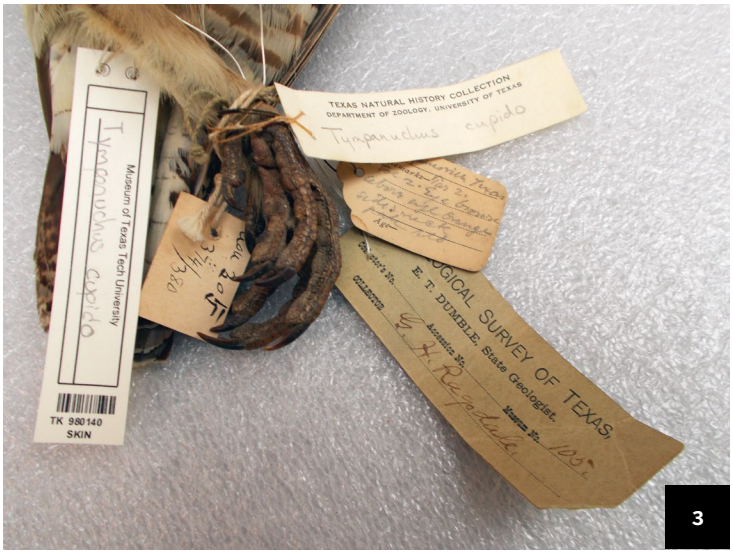
The Invertebrate Zoology Collection began "from nothing," according to a 1974 article by Dr. Robert Mitchell, Curator, in the *Museum Digest*. Mitchell explained that the collection, at that point, had been built almost entirely from fieldwork, as well as gifts from other scientists. At the time, the Medical Zoology Collection of parasites was recognized as a separate collection, curated by Dr. Danny Pence. For a time, the Medical Zoology Collection was transferred to the TTU Health Sciences Center, where Dr. Pence was on faculty. When it was reaccessioned by the Museum in 2003, it was incorporated into the Invertebrate Zoology Collection, thus growing the collection by ~70,000 new specimens. Similarly, the former Entomology Collection originally was curated by Dr. Robert W. Sites at the Department of Entomology (now Plant and Soil Sciences), and was transferred to the NSRL and merged with the Invertebrate Zoology Collection in 1997, adding ~465,000 insect specimens to the collection. Other periods of growth for the Invertebrate Zoology Collection include the accessioning of ~40,000 illegally collected or improperly imported specimens, primarily of beetles and butterflies, that



1



2



3

1. Vials of tissue samples obtained from a mammal specimen.

2. Preserved butterfly specimens that had been illegally collected, confiscated by USFWS agents, and placed in the care of the Invertebrate Zoology Collection of the NSRL.

3. Tags on a Greater Prairie Chicken specimen acquired during an exchange of collections with the Texas Memorial Museum.

had been confiscated by the USFWS and entrusted to the NSRL in 2001. Of course, field collecting and research by curators, faculty, research associates, and students continued to grow the collection, as well, throughout its history. These projects include, among others: noxious brush and weed control research (1970s); the Texas Tech Boll Weevil Project (1970s); a survey of the ants of western Texas (1978–1981); a study of mites from Mexico and Central America (2003); and studies of aquatic invertebrates from Texas playa lakes (more than one million specimens, 2004–2005) and insects of the Monahans Sand Dunes (~200,000 specimens, accessioned 2013). Currently, the **Invertebrate Zoology collection totals an estimated 4.6 million specimens**.

The **Bird Collection's holdings nearly doubled in 2005 when the NSRL acquired the historically important Texas Memorial Museum's collection**. A complete inventory of the collection was conducted in 2020–2022, during which data from the original NSRL bird collection and from the Texas Memorial Museum specimens were verified and merged to create a single master database. Plans for the near future include uploading these data to the NSRL's online, searchable portal as well as to the Global Biodiversity Information Facility (GBIF), the leading online access portal for data from collections around the world.

Throughout its history, **the NSRL facilities have undergone several renovations and expansions, funded by a combination of federal grants, donations, and institutional support, to accommodate the growth of its collections**. The first major renovation, supported by an NSF grant, occurred in 1997–1998. The project

The new wing of the NSRL, under construction in 2004.

improved workflow efficiency and enhanced the care of the collections by isolating the office, collections, and preparation areas. In addition, the GRC was expanded into a second room, doubling the space available for ultracold freezers. However, the rapid growth of the collections over the next few years, and expectations for continued growth in the years to come, necessitated an expansion of the physical footprint of the building. In 2000, Chancellor John T. Montford and President David J. Schmidly pledged $5 million of a major unrestricted gift to TTU to provide for an expansion of the NSRL. This commitment by TTU was made in recognition of the excellence achieved at the NSRL in research, education, and public outreach. The building addition, completed in 2005, more than doubled the size of the NSRL facilities to accommodate the growing collections, as well as to provide additional space for research and teaching activities, student offices, and an expanded library. The move into the newly dedicated space was accomplished with NSF support. In 2005, a matching donation from the Helen Jones Foundation allowed for the purchase of 200+ additional cases and cabinets to further expand the storage capacity of the Mammal and Bird Collections. Most recently, the renovation of the GRC to transfer the collection from mechanical ultracold freezers to liquid nitrogen storage, a project funded by both NSF and TTU, allowed for increased storage capacity within the facility while fulfilling the NSRL's commitment to the highest quality of preservation of this vital research collection.

The NSRL has, since its establishment, been recognized by the scientific community as a leader in collections management and curatorial practices. Stephen L. Williams, Collection Data Analyst (1975–1976) and Collection Manager for the NSRL (1990–1995), was one of the most prolific early authors of papers regarding the collecting of mammals and the preservation of natural history collections. He was particularly active in the testing and development of new techniques for preservation and developed many scientific standards for collections. Of the 134 published papers he authored during his career, **80 were on the topics of collecting, collections management, preservation techniques, museum policy, and ethics and professionalism in natural history collections**. Thus, they are too numerous to list here, but a few of his most significant include:

Williams, S. L. 1999. Destructive preservation: a review of the effect of standard preservation practices on the future use of natural history collections. Göteborg Studies in Conservation, Volume 6. Acta Universitatis Gothoburgensis, Sweden. 206 pp.

Williams, S. L., and C. A. Hawks (editors). 2006. Museum studies: perspectives and innovations. Society for the Preservation of Natural History Collections, Washington, DC. 281 pp.

Williams, S. L., R. Laubach, and H. H. Genoways. 1977. A guide to the management of Recent Mammal

collections. Carnegie Museum of Natural History, Special Publication No. 4. 104 pp.

Additionally, Drs. Baker, Bradley, Phillips, and other Museum and NSRL staff have published numerous well-recognized papers regarding the value and significance of natural history collections, the establishment of techniques, standards, and best practices for such collections, and long-term preservation of samples. These include:

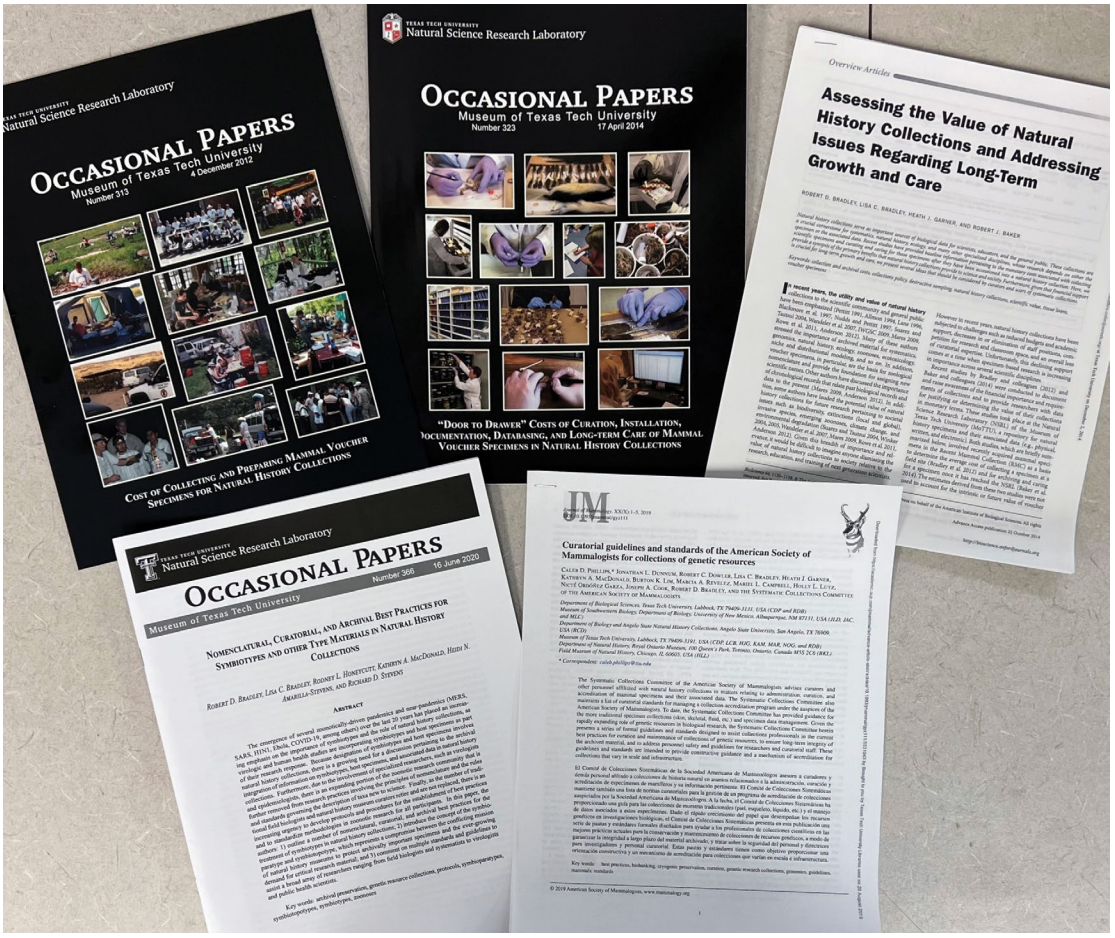
Amarilla-Stevens, H. N., R. D. Stevens, C. D. Phillips, and R. D. Bradley. Temporal rate of post-mortem DNA degradation in archived tissue samples: evidence from liver and muscle. Journal of Mammalogy, in press.

Baker, R. J., L. C. Bradley, H. J. Garner, and R. D. Bradley. 2014. "Door to drawer" costs of curation, installation, documentation, databasing, and long-term care of mammal voucher specimens in natural history collections. Occasional Papers, Museum of Texas Tech University 323:1-15.

Bradley, R. D., L C. Bradley, H. J. Garner, and R. J. Baker. 2014. Assessing the value of natural history collections and addressing issues regarding long-term growth and care. BioScience 64:1150-1158.

Bradley, R. D., L. C. Bradley, H. J. Garner, and R. J. Baker. 2012. Cost of collecting and preparing mammal voucher specimens for natural history collections. Occasional Papers, Museum of Texas Tech University 313:1-14.

Bradley, R. D., L. C. Bradley, R. L. Honeycutt, K. A. MacDonald, H. N. Amarilla-Stevens, and R. D. Stevens. 2020. Nomenclatural, curatorial, and archival best practices for symbiotypes and other type material in natural history collections. Occasional Papers, Museum of Texas Tech University, 366:1-17.



Selection of papers authored by NSRL curators and staff regarding the value of collections and the establishment of standards for collections care.

Genoways, H. H. 1987. Mammal collection management. Texas Tech University Press. 219 pp.

King, R. D., R. R. Monk, and R. J. Baker. 2000. Electronic field data capture using WildCat III. Museology, Museum of Texas Tech University 9:1-8.

Ladkin, N. E. Johnson, R. J. Baker, and S. Chatterjee. 2011. The use of collections in research and teaching at the Museum of Texas Tech University. University Museums and Collections Journal 3:127-135.

Monk, R. R. 1998. Bar code use in the Mammal Collection at the Museum of Texas Tech University. Museology, Museum of Texas Tech University 8:1-8.

Monk, R. R. 2001. E-vouchers and the use of digital imagery in natural history collections. Museology, Museum of Texas Tech University 10:1-8.

Phillips, C. D., J. L. Dunnam, R. C. Dowler, L. C. Bradley, H. Garner, K. A. McDonald, B. K. Lim, M. A. Revelez, M. L. Campbell, H. L. Lutz, N. Ordóñez Garza, J. A. Cook, R. D. Bradley, and the Systematic Collections Committee of the American Society of Mammalogists. 2019. Curatorial guidelines and standards of the American Society of Mammalogists for collections of genetic resources. Journal of Mammalogy 100:1690-1694.

Soniat, T. J., H. Sihaloho, R. D. Stevens, T. D. Little, C. D. Phillips, and R. D. Bradley. 2021. Temporal-dependent effects of DNA degradation on frozen tissues archived at -80°C. Journal of Mammalogy 102:375-383.

The *Journal of Mammalogy* recognized the paper by Soniat et al. as its "Editor's Choice" selection in the April 2021 issue of the journal. The Editor's Choice commentary highlighted the value of the NSRL's research and the importance of natural history collections, especially genetic collections such as the Robert J. Baker Genetic Resources Collection. The editorial also cited the manuscripts by Bradley et al. (2020) and Phillips et al. (2019), which further signifies the NSRL as a leader in this field. Taylor Soniat was a Master's student of Dr. Bradley, and he currently is employed as a Collections Specialist at the primary biorepository of the CDC.

As testament to the professional curatorial standards maintained by the NSRL, **both the Mammal Collection and the Genetic Resources Collection are accredited by the American Society of Mammalogists**. The GRC was the first such collection to receive this accreditation by the Society (2019). Further, as a division of the Museum, the NSRL is accredited by the American Alliance of Museums.

In the late 1960's, Dr. Robert J. Baker developed the "TK" system of assigning a unique number, prefaced by TK, to each individual specimen as they were collected in the field or as they came into the NSRL, with the same TK number used for all parts and preparation types of that individual (e.g., skin, skull, skeleton, tissues). TK was, depending upon whom you asked, short for "[Texas] Tech Karyotypes" or "Tissues and Karyotypes." The system is still in use today for tracking all materials in the field and in the NSRL facility, thus linking all related parts of an individual throughout the process of collecting, preparing, curating, cataloging, and incorporating materials into the collections. Further, the system is particularly useful for maintaining an inventory of genetic resource materials and linking them to the corresponding specimens, because unlike voucher materials, GRC samples are not assigned catalog numbers. **The TK system originated by Dr. Baker was soon adopted by multiple other natural history museums** (e.g., University of New Mexico Museum of Southwestern Biology = "NK"; Texas A&M Biodiversity Research and Teaching Collections = "AK"; Angelo State Natural History Collections = "ASK"; Carnegie Museum of Natural History = "SP").

Dr. Richard Monk, former Curator of Collections for the NSRL, initiated a Data Enhancement Project in 1996. This project included transforming the existing flat database into a relational database, known as *WildCat*, for data capture both in the field and in-house, publishing one of the first searchable mammal collections on the web by 1997, and adding barcodes on mammal specimen tags and tissue tube labels. The NSRL was one of the first Museum collections in the US to implement barcodes broadly throughout collections, using them to reduce transcription errors of specimen data and reduce potential thawing of frozen samples during processing. Through the years, the data management systems at the NSRL have been modified as software, technology, and natural history disciplines have changed. The initial relational database designed by Dr. Monk was rewritten and expanded upon by Heath Garner, current Curator of

The Systematic Collections Committee
of the
American Society of Mammalogists
having reviewed the mammal collection at the
Natural Science Research Laboratory
Museum of Texas Tech University
HEREBY ACKNOWLEDGES that this collection meets the curatorial standards for systematic collections as established by the Society, and accordingly issues this
Certificate of Accreditation
Robert S. Sikes, President
American Society of Mammalogists
Robert C. Dowler, Chair
Systematic Collections Committ
10 July 2017
Date

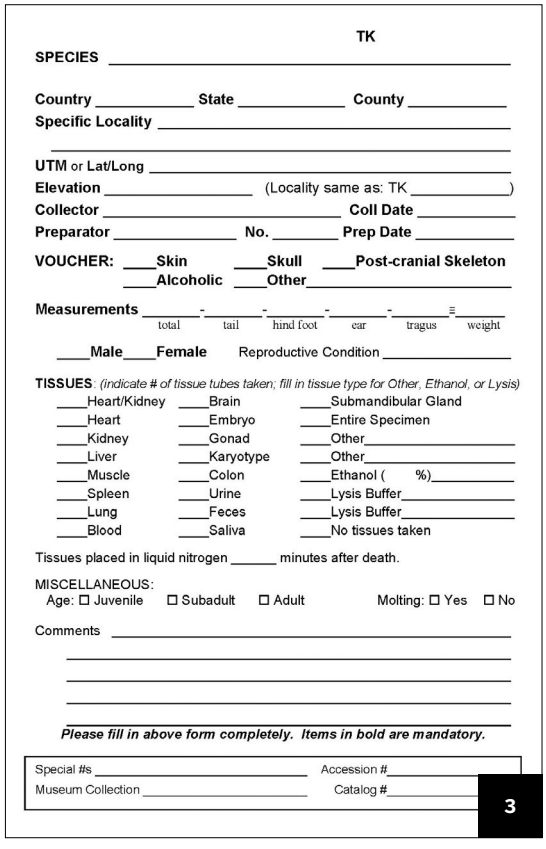
1

The Systematic Collections Committee
of the
American Society of Mammalogists
having reviewed the genetic resources collection
at the
Natural Science Research Laboratory,
Museum of Texas Tech University
HEREBY ACKNOWLEDGES that this collection meets the curatorial standards for systematic collections as established by the Society, and accordingly issues this
Certificate of Accreditation
Douglas A. Kelt, President
American Society of Mammalogists
Jonathan L. Dunnum, Chair
Systematic Collections Committee
15 December 2019
Date

2

Collections (see Appendix B: *Current Staff Profiles*), to track additional digital assets such as field notes, loan records, and GenBank numbers, as well as recording comprehensive notes about collecting, specimen reproduction, inventory details, and other metadata. Barcodes, digitized records, and robust, relational databases continue to be essential for facilitating the research of those utilizing the NSRL's collections.

More recently, **the NSRL has been active in several projects using advanced methods of collection digitization and databasing**. In 2012, James C. Cokendolpher, Curator of the Invertebrate Zoology Collection at the time, was a PI on a collaborative NSF grant to digitize and enter records of arthropods of the southwestern US into the Symbiota Collections of Arthropods Network (SCAN). Dr. Jennifer Girón, current Acting Collections Manager, and her team of students and volunteers have continued to enter records into this data portal, which now contains more than 179,000 TTU specimen records, 82% of which are georeferenced, and nearly 26,000 images. Recently, Dr. Girón and Dr. Scott Longing, faculty member of the Plant and Soil Science Department, were awarded funding by the Texas Parks and Wildlife Department to digitize 17,000 bee specimens that had been collected since 2015 from the High Plains region of western Texas. In 2021, Drs. Richard D. Stevens and Robert D. Bradley were awarded an NSF grant to generate high-resolution computerized tomography (CT) scans of entire museum specimens of phyllostomid bats to facilitate functional trait diversity analysis. Dr. Stevens and Bradley also are PIs on another collaborative NSF proposal that has been recommended for funding to digitize and mobilize specimen-level trait data for all non-marine mammal species of the western United States. Such collaborative, large-scale digitization efforts fulfill the mission of NSF's Division of Biological Infrastructure to create a robust national infrastructure that advances fundamental biological research.



TK

SPECIES _____

Country _____ **State** _____ **County** _____
Specific Locality _____
_____

UTM or **Lat/Long** _____
Elevation _____ (Locality same as: TK _____)
Collector _____ **Coll Date** _____
Preparator _____ **No.** _____ **Prep Date** _____

VOUCHER: ____**Skin** ____**Skull** ____**Post-cranial Skeleton**
____**Alcoholic** ____**Other**_____

Measurements _____-_____-_____-_____-_____≡_____
total tail hind foot ear tragus weight

____**Male**____**Female** Reproductive Condition _____

TISSUES: *(indicate # of tissue tubes taken; fill in tissue type for Other, Ethanol, or Lysis)*

____Heart/Kidney	____Brain	____Submandibular Gland
____Heart	____Embryo	____Entire Specimen
____Kidney	____Gonad	____Other_____
____Liver	____Karyotype	____Other_____
____Muscle	____Colon	____Ethanol (%)_____
____Spleen	____Urine	____Lysis Buffer_____
____Lung	____Feces	____Lysis Buffer_____
____Blood	____Saliva	____No tissues taken

Tissues placed in liquid nitrogen _____ minutes after death.

MISCELLANEOUS:
Age: ☐ Juvenile ☐ Subadult ☐ Adult Molting: ☐ Yes ☐ No

Comments _____
_____
_____
_____
_____

Please fill in above form completely. Items in bold are mandatory.

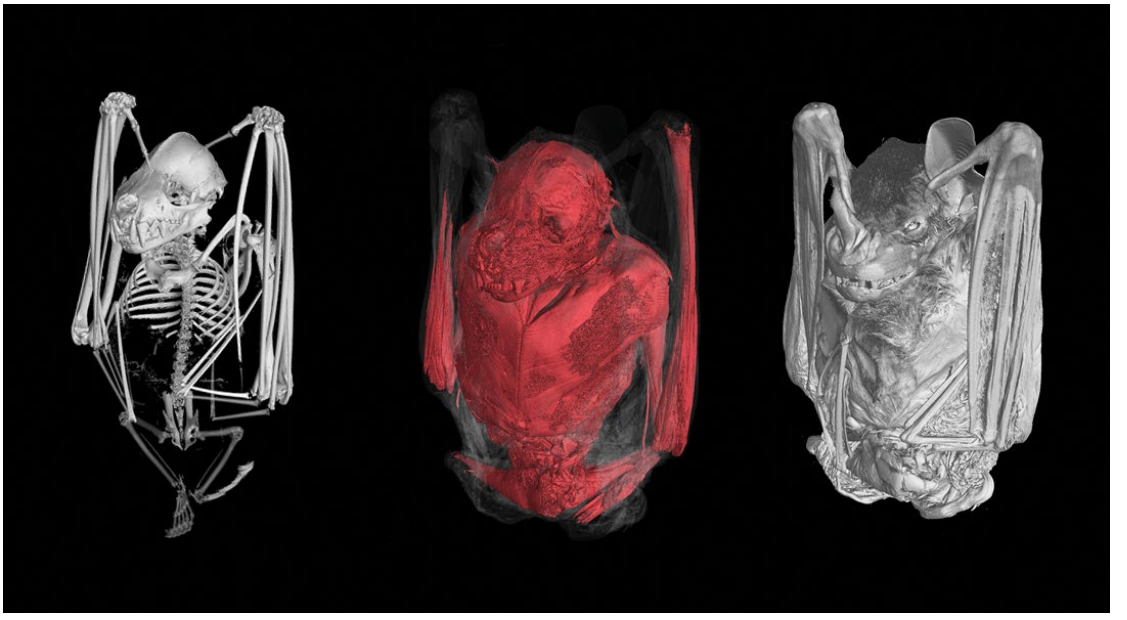
Special #s _____ Accession #_____
Museum Collection _____ Catalog #_____

3

1. ASM certificate of accreditation of the Mammal Collection, 2017

2. ASM certificate of accreditation of the Genetic Resources Collection, 2019

3. The current TK page template of the NSRL Mammal Collection.

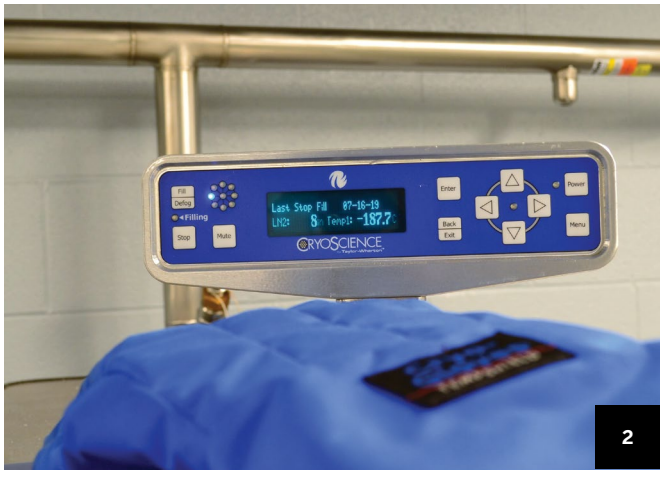


A CT scan of Artibeus jamaicensis resulting from a current NSF-funded research grant to Drs. Richard Stevens and Robert Bradley.

Perhaps the most significant recent example of the priority that the NSRL places on collections care and preservation is its conversion of its Genetic Resource Collection to a liquid nitrogen storage system. Since its establishment in the 1970s, the GRC had relied upon traditional -80°C mechanical freezers for the storage of its frozen samples. However, these freezers have a short lifespan and are subject to frequent malfunction or complete failure, as well as to power outages, thus putting samples at risk for degradation or total loss. More importantly, many current and developing scientific research techniques and disciplines require that tissue samples be preserved at temperatures below -132°C to preserve the entire spectrum of genomic data they contain (e.g., RNA, viruses, bacteria). Storage in liquid nitrogen (LN2), which maintains samples near -190°C, thus has become the "gold standard" for preservation of tissue collections. In 2015, Robert D. Bradley and the late Robert J. Baker received a grant from the Collections in Support of Biological Research program of the NSF, supplemented by funding from the TTU Offices of the President and the Provost, to purchase and install a liquid nitrogen system. The transfer of frozen tissues to vapor-phase liquid nitrogen freezers would ensure the collection's long-term preservation and availability for scientific research. After necessary renovations of the GRC facility, four large freezers and one small freezer (exclusively for the Chernobyl Radioactive Collection) were purchased and installed. In 2018, a sixth large freezer was added after the NSRL received funding from the Wolcott family for the archiving of wound microbiome samples, and from the Wild Sheep Foundation for archiving North American bighorn sheep samples.

The process of transferring tissues to new boxes and installing them into the LN2 freezers was time and labor intensive, but it allowed for confirmation and updating of the GRC's existing inventory of the tissue collection, as well as the upgrading of some vials with new label stock and barcodes. Kathy MacDonald, Collections Manager of the GRC (see Appendix B: *Current Staff Profiles*) managed the project workflow, trained and supervised the student assistants, and ensured that the NSRL was incorporating the best museum practices in tissue archival and database methodologies as the transition took place.

Other outcomes of this NSF project included: expanded storage capacity of the GRC, allowing for growth of the collection; annotation of the NSRL public database with genetic sequence database numbers; annotation of the NSRL's internal database to indicate samples obtained from virus-positive vouchers, consolidation of virus-positive samples, and designation of the boxes containing those samples with color-coded labels; labeling of symbiotype and holotype genetic samples with color-coded labels; education and training of graduate and undergraduate students in collection management practices; a public exhibit highlighting the significance of genetic resource collections to science



and society; testing of cryolabels and other archival supplies; and reduced energy consumption by the transition to a green technology.

Over the course of the grant period, nine graduate students received training and experience in the GRC while contributing a total of 8,643 hours of effort toward processing, inventorying, databasing, and installing samples. A total of 292,751 samples, comprised of those previously housed in -80°C mechanical freezers as well as new samples accessioned over the course of the grant period, were installed in the five liquid nitrogen freezers. **The collection in liquid nitrogen has now grown to more than 349,000 samples** (remaining samples in the GRC are held at room temperature, -20°C, or -80°C, as appropriate for the type of sample). Most importantly, this LN2 conversion project provided for the long-term protection of the current and future samples in the GRC and ensures that the collection can supply the scientific community with the highest quality genetic materials for research.

A dedication to best practices for the growth and care of natural history collections has been a priority of the NSRL since it was established, and it remains a priority for the current curators, staff, students, and associates of the NSRL. It is impossible to quantify or predict the value of these collections to science. Each specimen or tissue is an irreplaceable record of that organism's existence at a specific place and time, and advancements in research and technology are continually revealing new insights into these collections and their importance in understanding biodiversity and the implications for science and society. **The NSRL, upon accepting specimens and samples into its care, is charged with the preservation of that material and its data in perpetuity**. The NSRL does not take that charge lightly. The personnel of the NSRL are committed to maintaining the highest standards of preservation and thus providing for the greatest utility of its collections in the years to come.

1. Vials of frozen tissue samples

2. Controller for a liquid nitrogen freezer showing internal temperature

3. Racks in LN2 freezer

Public Engagement and Outreach

The NSRL recognizes that **public engagement and outreach are important components of its mission and that these activities provide a valuable service to the Texas Tech community, K-12 schools and colleges, visitors to the Museum, and the general public**. For many local and regional visitors, Museum exhibits and outreach activities may be the only in-person opportunities these individuals have to engage with science and natural history discovery.

The staff members of the NSRL frequently develop **exhibits for display in the public galleries of the Museum**. In 2020, a new gallery was developed that is devoted to a long-term NSRL exhibit, "Biodiversity of the Llano Estacado." Such **science and nature-based exhibits are among the most popular with visitors to the Museum**. Other NSRL-based exhibits in recent years have included:

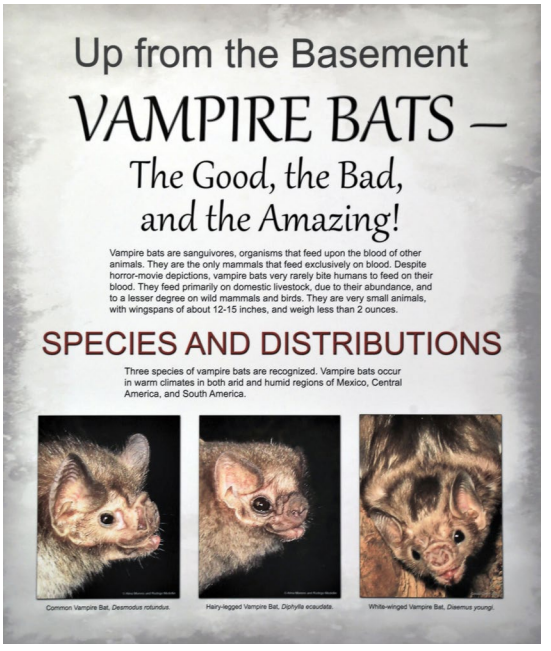
2022, "Tiny and Mighty Creatures," an exhibit of more than 100 specimens from the Invertebrate Zoology Collection, accompanied by online content via a QR code link to the NSRL website;

2019, "Frozen in Time," an exhibit about genetic resource collections and their importance to science;

Entrance to the long-term exhibit "Biodiversity of the Llano Estacado," 2020.

A recent exhibit of the Invertebrate Zoology Collection. The QR code takes visitors to a wealth of information online.

The exhibit "Frozen in Time" illustrated the value of genetic resource collections to science and society.



Opening text panel for a 2014 exhibit about vampire bats

2018, "Grasslands of North America and Africa," comparing the habitats and wildlife of each region;

2016, "In the Blood", an exhibit primarily about vampires and werewolves – the NSRL contributions to this exhibit were the factual components about vampire bats and wolves, blood-sucking invertebrates, the "chubacabra" legend, current research projects at TTU in blood pathology and chemistry, and more;

2015, "Antarctica" – the NSRL contributed information about numerous mammal and bird species of Antarctica;

2014, "Vampire Bats: The Good, the Bad, and the Amazing", an exhibit that opened near Halloween and included a well-attended family-focused event with a guest lecture by a vampire bat biologist, craft activities for children, and take-home materials;

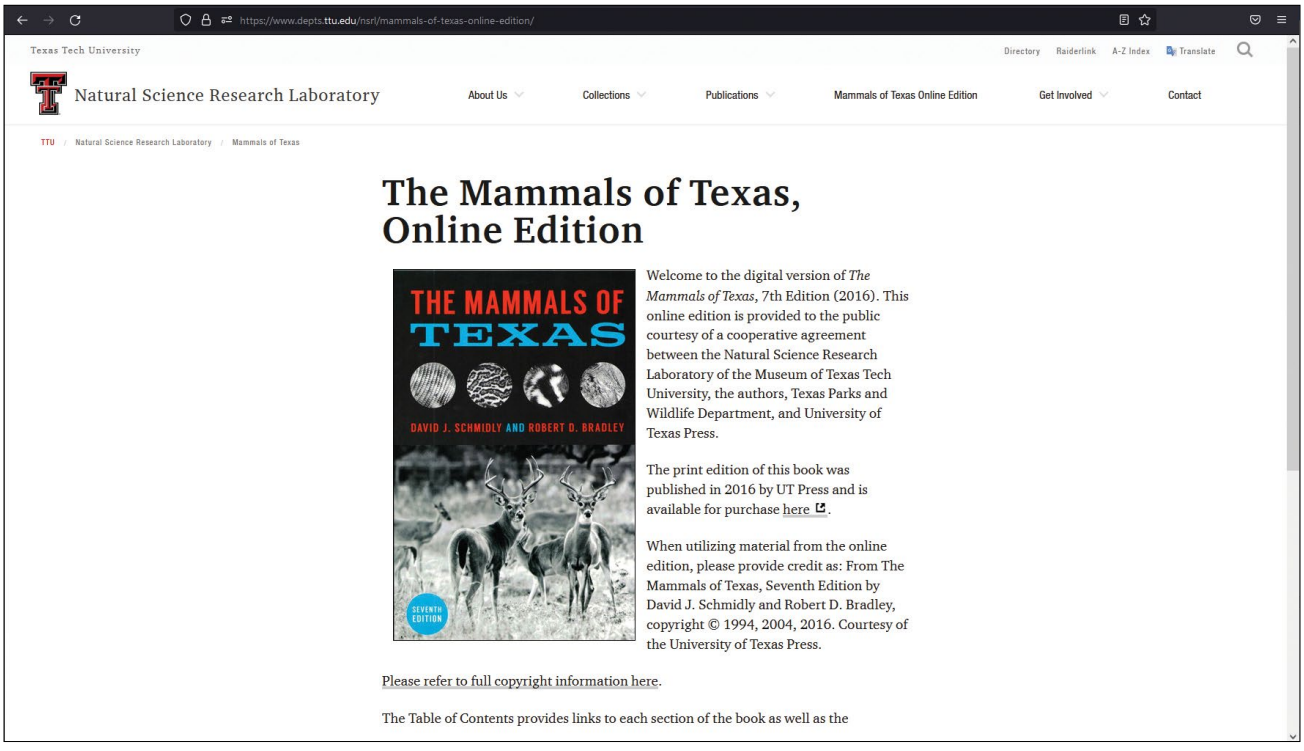
2013, "From Numerous to Non-existent: Common, Rare, Threatened, Endangered, and Extinct Species in the Collections of the Natural Science Research Laboratory," an exhibit that accompanied the "Rare" exhibit of photographs by acclaimed nature photographer Joel Sartore.

The NSRL **also engages the scientific community (worldwide), K-12 and college students, and the general public via its website**, <www.depts.ttu.edu/nsrl>. The website contains information about the NSRL's mission and purpose, collections, curators and staff, publications, "news" about recent NSRL happenings, and more. The website provides online access to our searchable Mammal Specimen Database, which contains information about all of our cataloged mammals. The database is used primarily by researchers to obtain data and to determine the availability of specimens or tissues they wish to borrow for their research. The website also contains access to all of our published *Occasional Papers* and *Special Publications*, available for free download as PDFs, and instructions for authors that wish to submit manuscripts for consideration. Our publications are used as reference materials by researchers, students, and the general public. One of the most frequently used assets of the NSRL website is the digital version of *The Mammals of Texas* (2016), authored by Dr. David J. Schmidly (former TTU President and an NSRL Research Associate) and Dr. Robert D. Bradley (NSRL Director), and made available courtesy of an agreement with University of Texas Press and Texas Parks and Wildlife Department. This popular reference book is used by the scientific community, amateur naturalists, teachers, and schoolchildren for information about the diverse mammalian fauna of Texas. The webpages of *The Mammals of Texas* receive an average of 167 page views per day.

The NSRL website also contains links to our **newsletter**, which is distributed to our mailing list of Research Associates, former students, and other colleagues in science. The NSRL newsletter highlights the recent activities and accomplishments of the NSRL, including feature stories about research projects, lists of publications by our affiliated faculty, staff, and students, lists of research grants, news of upcoming events, and more.

The NSRL Curators and staff further **engage with the public** via many other means, including:

- posts and videos on the Museum's social media outlets (Facebook, Twitter, YouTube, Instagram);
- articles featured in the M magazine of the Museum;
- local television news coverage of NSRL activities;
- in-person outreach activities for schools and civic groups (recent examples include invited presentations at STEAM Camp, Conservation Academy at



The NSRL website features the online edition of The Mammals of Texas, an excellent reference for K-12 students, college students, and professional biologists alike.

Lubbock Lake Landmark, Llano Estacado Audubon Society, South Plains Master Naturalist, and participation in various workshops, panels, and webinars);

- an iNaturalist project (i.e., citizen science) to document invertebrates that occur in the Museum Arroyo and elsewhere on the Museum property;
- volunteer opportunities at the NSRL;
- class tours by K-12 and non-TTU college classes (e.g., South Plains College, Seminole High School);
- public events at the Museum (e.g., book signings; public lectures; "Bat Day" celebration).

A current goal of the NSRL, pending donations or other sources of support, is to create a *Hall of Biodiversity* in the atrium and adjoining areas of the NSRL, and to have that area available for tours by Museum visitors. This endeavor would, for the first time, **open the NSRL to visitors for in-house engagement on a regular basis**. The *Hall of Biodiversity* would feature an impressive display of nearly all of the NSRL's taxidermy mammal and bird specimens, which would be hung from beams installed on the two-story wall of the Atrium and would be accompanied by labels and natural history facts about each species. The exhibit also would feature full-body taxidermy specimens along the hallways of the NSRL, display cases featuring representatives from the Invertebrate Zoology collection, and a wealth of information available in both printed form and via QR codes. The QR codes would allow visitors to continue their learning and engagement experience online, at their leisure. To expand the NSRL's outreach efforts, the QR codes and its related online information, including a "virtual tour" of the exhibit, also would be available to the general public, including schools, to reach individuals that cannot visit the Museum in person. We are actively engaged in fundraising efforts to make the *Hall of Biodiversity* a reality in the near future. This proposed exhibit would have a significant impact on the public engagement and outreach mission of the NSRL, Museum, and Texas Tech University.

Museum of Texas Tech University
Apr 17, 2021 ·

It's #InternationalBatAppreciationDay! This is a Spotted Bat (Euderma maculatum) from the Mammal Collection of the Museum's Natural Science Research Laboratory (NSRL). This bat was the 150,000th specimen to be cataloged into the collection.
#themott #museumofttu #museumoftexastech #texastechmuseum #museums #lubbock #westtexas #mammalcollection #mammals #research #spottedbat #texastechuniversity #texastech #ttu

Erin Stukenholtz and 50 others

51 4 1

Museum of Texas Tech University
Apr 19 ·

Biodiversity of the Llano Estacado is a permanent exhibition that features an in depth look at this living landscape and explores the importance of biodiversity and the seven major habitats which supports a variety of wildlife. The exhibition highlights wildlife education and research done by the Natural Science Research Laboratory.

Ruth Cruz and 32 others

33 6

Museum of Texas Tech University
May 20, 2021 ·

A great article that explains the purpose and important work our Natural Science Research Laboratory (NSRL) does!

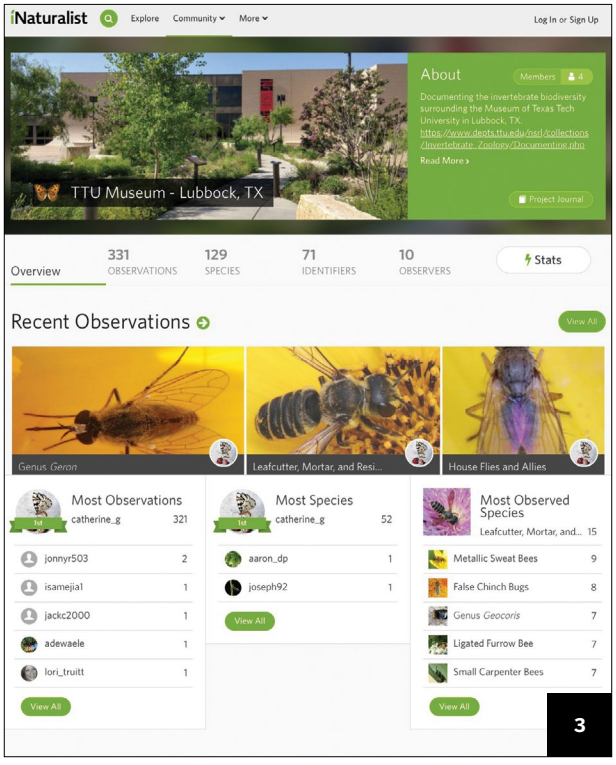
"Our job is to preserve [samples] - in the best way we can - to try to anticipate what future methodologies we'll need, so that research of the future have a historic dataset to back and look at." Dr. Robert Bradley, Director, NSRL

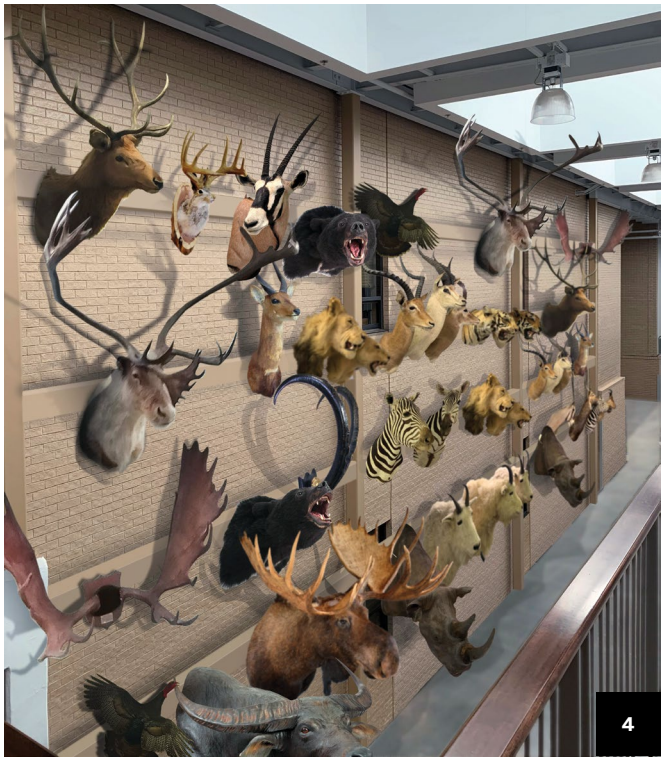
Thank you to The Academic Times!

academictimes.com
DNA galleries curated in liquid nitrogen preserve biological data for decades

1

2





1. A selection of Facebook posts regarding the NSRL.

2. Students viewing invertebrate specimens during a "Conservation Academy" event at the Lubbock Lake Landmark.

3. The iNaturalist page where the public can document observations of invertebrates at the Museum of TTU.

4. A concept illustration for the proposed "Hall of Biodiversity" in the NSRL.

Conclusion

The NSRL remains one of a small number of specimen-based collections that have maintained or increased numbers of specimen accessions for more than half a century by investing significant effort and resources to support a minimal staff and to overcome funding limitations. As demonstrated in this report, museum specimens archived in the NSRL have proved to be important for characterizing evolutionary processes, understanding the impacts of environmental change on ecosystems and landscapes, exploring the ecology of emerging diseases, and contributing to effective conservation and wildlife management policy. The inherent value of preserving and archiving representative vouchers and genetic samples from wild populations will become even more important in the 21st century as society wrestles with climate change and the biodiversity crisis.

The directors, curators, staff, students, and others affiliated with the Museum and the NSRL, throughout its 50-year history, have always taken great pride in the NSRL's accomplishments in research, education, scholarly output, collections growth and care, and public engagement. As evidenced by the testimonials in this report, the NSRL also is respected by our peers in the natural history collections and scientific research communities for its value as an important archive of biological diversity and for its direct contributions to science and education. We look forward to a bright future, for the next 50 years and beyond, as a valuable and impactful component of the Museum and Texas Tech University.

For more info about the NSRL

Appendix A: *Current Collection Profiles*

MAMMAL COLLECTION

The Mammal collection currently contains >156,500 specimens of >1,400 species. Based on a 2017 survey by the American Society of Mammalogists, it is ranked 4th in size among academic-affiliated mammal collections in the US, and 7th in size of all mammal collections (including non-academic institutions) in the Western Hemisphere. Specimen preparation types include preserved skins, skeletal materials, alcohol-preserved specimens, and taxidermy mounts. The collection also includes a unique group of >3,000 low-dose radioactive specimens collected by TTU researchers from 1994 to 2004 from the region of the 1986 Chernobyl nuclear disaster in Ukraine. The Mammal Collection is one of the fastest growing in the United States, reaching milestones of 50,000 specimens in 1988; 100,000 in 2003; and 150,000 in 2019. Despite increasing restrictions on collecting, especially internationally, the collection also continues to grow in taxonomic and geographic diversity through the research endeavors of NSRL curators and research associates. The collection's primary taxonomic strength is in its large representation of rodents and bats, the two largest and most diverse groups of mammals in the world. The NSRL provides an average of 23 loans of 430 total mammal specimens per year to researchers worldwide. Specimens also are available to visiting researchers to examine, measure, photograph, and otherwise study on-site. The collection was accredited by the American Society of Mammalogists in 1975, and has maintained that accreditation to present. The Mammal Collection database is available online via the NSRL's website, VertNet, GBIF, and other data portals. In 2021, the NSRL received NSF funding as part of a multi-institutional digitization project to generate high-resolution computerized tomography scans of NSRL specimens of bats in the Neotropical family Phyllostomidae. Currently, a second collaborative NSF proposal to digitize and mobilize data from thousands of mammal specimens from the western U.S. has been recommended for funding.

ROBERT J. BAKER GENETIC RESOURCES COLLECTION

The Robert J. Baker Genetic Resources Collection (GRC) contains >470,000 samples of tissues, blood, and DNA from >110,000 specimens of mammals and other taxa. It is the 2nd largest genetic resource collection at a U.S. academic institution (and possibly the world), and it is one of only a few academic wildlife tissue collections stored in state-of-the-art liquid nitrogen freezers. The GRC is the fastest growing and the most highly used collection of the NSRL. The NSRL collects and archives more tissue types than other comparable genetic resource collections, thus expanding the research questions that can be addressed by utilizing the samples and making the GRC a particularly valuable resource for researchers. From 2010 to 2019, the collection grew by >120,000 genetic samples obtained from nearly 27,000 individuals. The GRC loans an average of >1,400 samples per year to qualified researchers around the world.

The GRC contains four subcollections, three of which continue to actively grow in size.

1. The largest subcollection is the Biodiversity collection. These samples have been obtained from wildlife specimens collected since before the establishment of the NSRL and are used for a variety of scientific research purposes. This collection continues to grow as a result of research by TTU faculty, staff, and students as well as collecting efforts by Research Associates of the NSRL at other institutions. A large proportion of the samples in this subcollection were obtained from specimen vouchers housed in the Mammal Collection. However, this subcollection also includes samples obtained from specimens in the Bird Collection and Invertebrate Zoology Collection, live animals (e.g., blood, ear clips, swabs), and mammal vouchers housed at other institutions that do not have genetic resource collection facilities. In line with the Mammal Collection of traditional

specimens, the collection's primary taxonomic strength is in rodents and bats. Significantly, rodents and bats also are the two mammal groups most associated with zoonotic emergent diseases.

2. The Wolcott Wound Care collection is an archive of microbiome samples (e.g., bacteria, fungi) from chronic human wounds that require extra medical intervention to heal. These microbiome samples are collected by doctors at the Southwest Regional Wound Care Center in Lubbock and are archived in the GRC for research purposes. This is an actively utilized research collection and it is the basis for a current NIH research proposal.

3. The Bighorn Sheep Collection was established when the NSRL was designated by the Wild Sheep Foundation and Texas Bighorn Society as the official repository for samples associated with studies of North American bighorn sheep. This collection is expected to grow in perpetuity as the result of continued research efforts on these species.

4. The Chernobyl collection contains 14,371 low-dose radioactive tissues obtained from specimens collected during TTU's research efforts in Chernobyl. Although collecting efforts in this region concluded in 2011, these unique samples are available for continued study in perpetuity.

BIRD COLLECTION

At >6,000 specimens, the Bird Collection is the 2nd largest ornithology collection in Texas. The Bird Collection consists of skins, skeletal material, alcohol-preserved specimens, nests, eggs, and taxidermy mounts. The Bird Collection includes members from every extant avian order worldwide, but its particular strength is as a representative collection of the amazing diversity of birds that occur in Texas. Most new additions are either from the South Plains Wildlife Rehabilitation Center in Lubbock (orphaned or injured birds that did not survive) or salvaged birds (road kills, window kills, cat kills) collected by personnel affiliated with Texas Tech University who have the appropriate federal and state permits. The Bird Collection also acquires specimens by trade with other institutions, taxidermy mounts donated by private individuals, and materials (whole birds, feathers, eggs, and nests) confiscated by authorities from cases involving poaching or illegal trade of animal parts. The collection loans an average of 170 specimens per year, primarily for teaching purposes. In a unique use of the collection, the specimens also are used by local artists; for example, Garland Weeks, a sculptor, and R. G. Box, a blacksmith artist, have both used specimens as models for their art, and a TTU Honors College course borrows specimens each year for students to use as subjects for drawings.

INVERTEBRATE ZOOLOGY COLLECTION

The Invertebrate Zoology Collection contains >4.6 million specimens. It is the 3rd largest invertebrate collection of the 12 such collections in the state of Texas. The collection is international in scope, with an emphasis on arthropods—primarily insects and arachnids—from semi-arid and arid lands. The collection also contains an important collection of more than 33,000 medical/veterinary specimens of endo- and ectoparasites. Invertebrate specimens are preserved following standard museum practices by various methods: dry pinned or enveloped, in ethanol, in buffered formalin, on microscope slides, on SEM stubs, and frozen specimens archived in the GRC. The pinned collection alone contains over 3,200 genera and 7,500 identified species. At least three million specimens are retained as sealed mixed-bulk specimens in ethanol. Efforts to identify, curate, digitize, and catalog specimens are an ongoing process. The Invertebrate Zoology database, currently containing nearly 200,000 specimen records and more than 26,000 photographs, is accessible online via the Symbiota Collections of Arthropods Network (SCAN) portal and the Global Biodiversity Information Facility (GBIF). The Invertebrate Zoology collection actively loans specimens to scientists around the world for identification and research purposes. It also provides opportunities for professional development for undergraduate and graduate students in Biological Sciences, Plant and Soil Science, and Heritage and Museum Sciences, as well as opportunities for volunteering for the Lubbock community at large.

Appendix B: *Current Staff Profiles*

ROBERT D. BRADLEY, PhD
Director of the NSRL, Curator of Mammals, Professor of Biological Sciences

Dr. Bradley holds Bachelor of Science and Master of Science degrees from Texas A&M University and a PhD from Texas Tech University. He has been a faculty member in the TTU Department of Biological Sciences since 1994, Curator of Mammals since 1994, and Director of the NSRL since 2015. He also serves as the Managing Editor of the *Occasional Papers* and *Special Publications* of the NSRL. Dr. Bradley's primary research interests include systematics, molecular evolution, and phylogenetics in mammals, with a particular interest in the geomyid and cricetid rodents of the southwestern United States and Central America. His research program uses multiple datasets (morphology, chromosomes, DNA sequences, next generation sequencing methods, etc.) to examine speciation, adaptations, levels of genetic divergence among species, phylogeographic patterns, reproductive isolation, and other events that can be used to explain mechanisms that determine the natural history and distribution of organisms as well as the processes that lead to the generation of biodiversity. More recently, his research has entered into the field of mammalian genomics, particularly with using transcriptomics and whole genome sequencing to identify potential speciation genes and genes affiliated with adaptations and determine evolutionary relationships among mammalian species. Other research topics include zoonoses and wildlife diseases; natural history collection growth, management, and utilization; bioinformatics; and the Genetic Species Concept. Two publications he authored on the latter topic are regarded as classics in mammalian systematics and have been referenced more than 1,800 times.

Dr. Bradley has been a PI or co-PI on more than 35 federal, state, and other external grants totaling more than $4.3 million. He has authored, coauthored, or edited >200 peer-reviewed scientific papers and 5 books (including co-authoring *The Mammals of Texas* and *Texas Natural History in the 21st Century*), advised or co-advised 23 Master's and 13 PhD students to completion, and mentored more than 110 undergraduate students in his laboratory. He and his students have presented more than 350 papers at scientific meetings, and his graduate and undergraduate students have been awarded more than 60 grants, scholarships, and presentation awards.

CALEB D. PHILLIPS, PhD
Curator of Genetic Resources,
Associate Professor of Biological Sciences

Dr. Phillips holds Bachelor of Science and Master of Science degrees from Tarleton State University and a PhD from Purdue University. He has been a faculty member in the TTU Department of Biological Sciences and Curator of Genetic Resources since 2015.

Dr. Phillips' primary area of focus is the study of metagenomic and genomic evolution and function. His work in the field of metagenomics focuses on understanding the determinants of community assembly of microbiomes, and how microbiomes relate to health in wildlife and in humans. Current research projects include the study of assembly of bat microbiomes, as well as how people's genetics determine the composition of their chronic wound infections. The latter is being conducted in collaboration with the Southwest Regional Wound Care Center and involves the development of the Wolcott Wound Care Research Collection at the NSRL. He is also investigating how post-transcriptional regulation during craniofacial development by the RNA-binding protein, Musashi-2, may be important for normal development and morphological differences among species. Other projects focus on biodiversity and conservation of Texas mammals.

Since 2017, Dr. Phillips has been a PI or co-PI on 7 federal, state, and other grants totaling more than $1.8 million. He has authored or coauthored 44 peer-reviewed scientific papers, advised or co-advised 4 Master's and 2 PhD students to completion at TTU since 2015, and mentored 9 undergraduate students in his laboratory since 2016. He and his students have presented more than 40 papers at scientific meetings.

Dr. Stevens holds Bachelor of Science, Master of Science, and PhD degrees in Biology from Texas Tech University. He was on the faculty of Louisiana State University from 2005 to 2013, before joining the faculty of the Department of Natural Resources Management at TTU in 2014. He has served as Curator of Mammals for the NSRL since 2018. His research interests lie at the intersection of community ecology, macroecology, and biogeography but are grounded in collections-based research. Part of his work examines the basic community ecology of bats and rodents in Paraguay, California, Louisiana, New Mexico, and Texas—in particular the effects of species environment interactions, dispersal, seasonality and competition on the structure of communities. He uses morphometric approaches to characterize community structure, construct phenotypic measures of biodiversity, and to better understand the relationship between form and function as it pertains to the ecology of organisms. He is also interested in the mechanistic bases of broad-scale patterns in the structure and diversity of communities and how to use this information to better conserve the world's biota.

Since joining the faculty of TTU in 2014, Dr. Stevens has been a PI or Co-PI on 20 federal, state, and other external grants totaling $2.7 million. He has authored, coauthored, or edited a total of 119 peer-reviewed scientific papers and 11 book chapters, advised or co-advised 2 Master's and 7 PhD students to completion, and he has mentored 42 undergraduate students in his laboratory. He and his students have presented 200 papers at scientific meetings.

RICHARD STEVENS, PhD
Curator of Mammals,
Presidents Excellence in Research Professor and Professor of Natural Resources Management

NANCY E. McINTYRE, PhD
Curator of Birds, Professor of Biological Sciences

Dr. McIntyre holds a Bachelor of Science and Master of Science in Zoology from University of Georgia and a PhD in Ecology from Colorado State University. She has been on the faculty of the Department of Biological Sciences since 2000, and has served as Curator of Birds for the NSRL since 2006. Her research program is grounded in landscape ecology, the field that examines the interplay between environmental patterns and ecological processes; she recently finished a three-year term as President of the North American Chapter of the International Association for Landscape Ecology. More specifically, her research focuses on the ecological consequences of human land use/land cover change. She and her students use geospatial analytics to examine how human activities affect animals' access to resources in a heterogeneous and dynamic world.

Dr. McIntyre has been a PI or co-PI on more than 25 federal, state, and other external grants totaling more than $3.5 million. She has authored, coauthored, or edited 96 peer-reviewed scientific papers, book chapters, and books, advised or co-advised 14 graduate students to completion, and mentored 27 undergraduate students in her laboratory. She and her students have presented 160 papers at scientific meetings since 2000, and her graduate and undergraduate students have been awarded more than 95 grants, scholarships, and presentation awards.

JENNIFER C. GIRÓN, PhD
Acting Collections Manager and Research Aide, Invertebrate Zoology

Dr. Girón has a PhD in Ecology and Evolutionary Biology from the University of Kansas, a Master of Science in Biology from the University of Puerto Rico at Mayagüez, and a Bachelor of Science in Biology, with emphasis in Entomology, from the Universidad del Valle in Cali, Colombia. Her research interests include the morphology, taxonomy, biodiversity, and systematics of Neotropical beetles. She is also passionate about biological collections and biodiversity informatics. Dr. Girón became involved with the Invertebrate Zoology Collection of the NSRL as a volunteer in 2018 and was soon appointed as Acting Collections Manager and hired as a Research Aide. Her duties include processing loan requests and incoming accessions, organizing and curating the collection, and training students and volunteers in curatorial tasks, including the digitization of the collection's holdings. She is actively involved in research, as well as in engagement and outreach activities of the Museum and the Lubbock Lake Landmark, highlighting the Invertebrate Zoology Collection and its specimens. In the long term, her goal is to have an accessible, active, and well-curated collection that serves the TTU community, while enhancing research in the broad scientific community.

Dr. Girón has authored or co-authored a total of 33 peer-reviewed publications as well as three book chapters, and 13 checklist datasets since 2006. Along with coauthors, she has described 86 beetle species new to science. She has been recognized for her work in insect systematics with the Snodgrass Memorial Research Award of the Systematics, Evolution, and Biodiversity Section of the Entomological Society of America, and the Jean Theodore Lacordaire Prize by The Coleopterists Society. Recently, she was a Co-PI on a $70,000 proposal that has been recommended for funding by the Texas Parks and Wildlife Department. That project would digitize the bee holdings at TTU and includes DNA barcoding of certain species. Dr. Girón also builds community around her research interests by collaborating with researchers in Colombia to generate lists of beetle species from the country and by hosting annual meetings where weevil researchers around the globe get to share their work.

HEATH J. GARNER
Curator of Collections

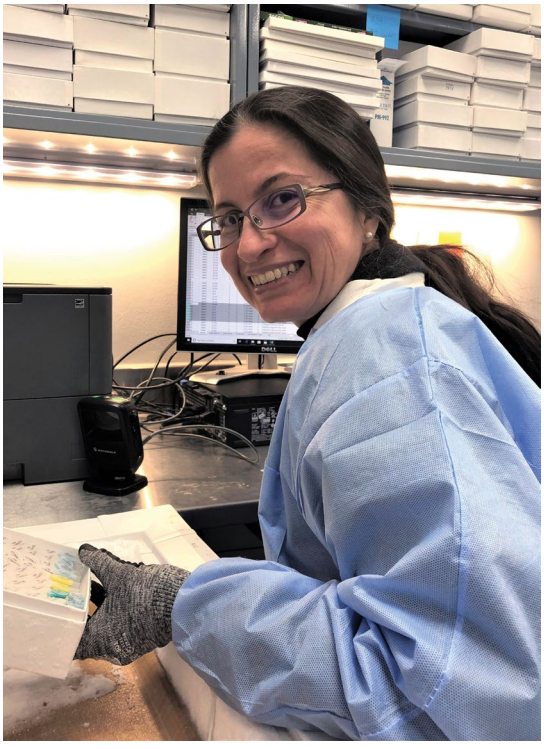
Heath Garner has a Master of Arts in Museum Science from Texas Tech University and a Bachelor of Science in Anthropology from the University of Houston. He has been with the NSRL since June of 2000. Heath facilitates the daily operations of the NSRL's collections. His duties include specimen processing, cataloging, and tracking, loan processing, student worker and volunteer training and supervision, documentation and record keeping, and collections preventative conservation. He has steered the digitization of collection records, led the efforts to barcode all mammal specimens collected prior to the NSRL's implementation of barcoding in 1995, and entered and assigned catalog numbers to more than 56,000 specimens. His professional interests are directed toward all aspects of natural history collection curation, data management, and the changing technologies in museum collections.

KATHRYN MacDONALD
Collections Manager, Robert J. Baker Genetic Resources Collection

Kathy MacDonald has a Master of Arts in Museum Science from Texas Tech University, a Bachelor of Science in Biology and a Bachelor of Science in Mathematics from the University of Texas of the Permian Basin, and an Associate of Applied Science degree in Veterinary Technology. Kathy began working at the NSRL in 2002, while a student in the Museum Science program. Kathy led the initial project to conduct a comprehensive inventory, reorganization, and modernization of the GRC in the early 2000s, and then started the initial push to seek funding for the transition of the collection to liquid nitrogen. During the NSF grant period (2016–2019), she oversaw the day-to-day execution of the transfer of samples to liquid nitrogen. Her primary duties at the NSRL include management of the Robert J. Baker Genetic Resources Collection and the training and supervision of its students and volunteers. On a daily basis, she is involved with the organization and processing of incoming samples as well as subsampling and processing of loans from the GRC. Other duties include assisting with specimen tracking in the collections, contributing to database management and design, performing information requests, and advocating for best museum practices.

LISA C. BRADLEY
Senior Research Associate and
Production Editor for Publications

Lisa Bradley holds a Master of Science in Wildlife Biology from Texas A&M University and a Bachelor of Science in Wildlife Science from West Virginia University. She has worked at the NSRL since 1996. Lisa's primary duty is the preparation of manuscripts for publication in the *Occasional Papers* and *Special Publications* series of the NSRL. She is responsible for communicating with authors and the editor through the review and revision process, copy editing, proofreading, and final layout and design. Lisa also edits and coauthors scientific articles and books published by NSRL staff and colleagues, assists in the preparation and submission of grant proposals, takes part in the development of NSRL-related exhibits for the Museum, and plans special events of the NSRL.



HEIDI AMARILLA-STEVENS
Research Aide

Heidi Amarilla-Stevens has a Master of Arts in Museum Science from Texas Tech University and a Bachelor of Science in Biology from the Universidad Nacional de Asunción in Paraguay. Heidi worked in the GRC from 2017 to 2020 while a student in the Museum Science program, and was hired as a Research Aide in 2021. Her duties at the NSRL include assisting in all aspects of the specimen curation process, preparing loans, training students, and long-term collections care. She also actively conducts research to improve curatorial practices as they relate to conservation of natural history species and genetic resource materials. Heidi's research interests center on the urgent need for both the preservation of natural history collections and the utilization of such collections for current and future research.

Appendix C: *Testimonials*

I was a Ph.D. student at Texas Tech University from September 1999 to May 2005 in Dr. Robert Bradley's lab, where I worked on phylogenetic systematics of peromycine rodents. We, as a lab, performed a lot of fieldwork and made many tissue, skin, and skeletal submissions to the NSRL throughout my time there. I was also fortunate enough to have access to the multitude of tissues stored at the NSRL, which greatly benefitted my research and enabled the completion of my dissertation work.

Dr. Bradley's lab collected specimens every year through a variety of projects, including Field Methods courses, Mammalogy courses, research projects at Chapparal Wildlife Management Area in Southwest Texas, the Sowell Expedition to Honduras in 2001, Leptospirosis surveillance at Gus Engeling Wildlife Management Area in east Texas, and Leishmania surveillance in several states in Mexico. I also collected small mammals in Colima, Mexico, for deposition at the NSRL through Dr. Robert Owen's lab.

I borrowed many tissue samples from the NSRL while completing my research projects in Dr. Bradley's lab at TTU. These borrowed tissues were crucial to the fulfilment of the research requirements of my doctoral degree and greatly facilitated the completion of several projects on rodent systematics I was involved with, including the following:

1. Amman BR, Bradley RD. 2004. Molecular evolution in *Baiomys* (Rodentia: Sigmodontinae): evidence for a genetic subdivision in *B. musculus*. Journal of Mammalogy 85:162-166.
2. Amman BR, Hanson JD, Longhofer LK, Hoofer SR, Bradley RD. 2006. Intron 2 of the alcohol dehydrogenase gene (Adh1-I2): a nuclear DNA marker for mammalian systematics. Occasional Papers, Museum of Texas Tech University 256:1-16.
3. Bradley RD, Schmidly DJ, Amman BR, Platt RN, Neumann KM, Huynh HM, et al. 2015. Molecular and morphologic data reveal multiple species in *Peromyscus pectoralis*. Journal of Mammalogy 96:446-459.
4. Platt RN, Amman BR, Keith MS, Thompson CW, Bradley RD. 2015. What Is *Peromyscus*? Evidence from nuclear and mitochondrial DNA sequences suggests the need for a new classification. Journal of Mammalogy 96:708-719.

I am also an author on 4 additional publications associated with the NSRL, 3 of which used samples borrowed from or deposited in the NSRL.

1. Haynie ML, Amman BR, Baxter BD, Durish ND, Hanson JD, Longhofer LK, et al. Mammal records from Donley and Briscoe Counties, Texas. 2005. Occasional Papers, Museum of Texas Tech University 247:1-4.
2. Suchecki JR, Amman BR, Baxter BD, Cajimat M, Carroll DS, Durish ND, et al. 2003. *Lasiurus ega* and other small mammal records from Dimmit and LaSalle Counties, Texas. Occasional Papers, Museum of Texas Tech University. 225:1-3.

3. Bradley LC, Amman BR, Brandt JC, McAliley LR, Mendez-Harclerode FM, Suchecki JR, et al. Mammalogy at Texas Tech University: a historical perspective. 2005. Occasional Papers, Museum of Texas Tech University 243:1-30.

4. Milazzo ML, Amman BR, Cajimat MN, Mendez-Harclerode FM, Suchecki JR, Hanson JD, et al. 2013. Ecology of Catarina virus (family Arenaviridae) in southern Texas, 2001-2004. Vector Borne Zoonotic Diseases 13:50-59.

The contributions to natural history research and knowledge made possible by the *Occasional Papers* and *Special Publications* series are outstanding, in that not only do these journals publish laboratory and field based research, they are also a great place to find range expansion papers, county records, new species accounts, and other material you cannot find in other journals. I have been an author on 5 papers published in Occasional Papers, 4 of which are listed above. The fifth is:

Amman BR, Owen RD, Bradley RD. 2002. Utility of hair structure for taxonomic discrimination in bats, with an example from the bats of Colorado. Occasional Papers, Museum of Texas Tech University 216:1-14.

My doctoral training through Dr. Bradley and the NSRL included laboratory skills, PCR, DNA extraction and sequencing, field collection of small mammals, museum preparation of skins and skeletons, tissue collection, cold chain maintenance of frozen samples, and archiving of specimens and samples. These skills I learned under the direction of Dr. Bradley and through the NSRL were responsible for me being hired by the Centers for Disease Control and Prevention's Viral Special Pathogens Branch to be their disease ecologist in the Virus Host Ecology Team. I have been in this position for 18 years, I have over 60 publications, and I was a co-team lead for the discovery of the Marburg virus natural reservoir. I could not have achieved any of this without the training I received from Dr. Bradley and the NSRL.

In my opinion, natural history collections are crucial to universities that have academic programs that focus on natural sciences. The contribution of the NSRL to my doctoral research and future career achievements were invaluable, not only to me, but the agency that currently employs me. Magnify this by the number of students the NSRL and other academic natural history collections have had an influence on, and the contributions to natural sciences and society are inestimable and priceless. These academic natural history collections should receive as much support as needed to continue their contributions to students, research, and natural history preservation for generations to come.

Brian R. Amman, PhD
Ecologist, Centers for Disease Control and Prevention

Beginning with my dissertation project at UT-Austin in 1988, I have borrowed hundreds of tissue specimens for both my projects and at least 22 student research projects (undergraduate and graduate) over the last 25 years on the evolution and species boundaries of mammals. Tissues from the NSRL have been important for the development of my career and an integral part of dozens of studies on bats, rabbits, shrews, and skunks that have been carried out in my research lab. Fifteen graduate student thesis projects (and these student's degrees) would not have been possible without that material. At least 7 undergraduate projects have included specimens from the NSRL. I also was involved in preparing many fluid-preserved bats and frozen tissues from the Texas Department of State Health Services as a result of two "field trips" with my students to the NSRL to work alongside NSRL workers. These specimens were deposited at the NSRL.

Of my publications, I count 25 that included NSRL-based tissue specimens or records of specimen occurrence from the database of holdings at the NSRL. Along with my coauthors, I have had 10 articles published in the *Occasional Papers* or *Special Publications* series. The quick turnaround time and the accessibility of the articles are the main reasons that I chose to submit manuscripts to the NSRL. Many of the publications in the *Occasional Papers* series contained important information about bat species that was used in the book, *Bats of Texas*, which was coauthored with Chris Hice and David Schmidly.

As a museum Curator at Angelo State University, I understand the work and expense involved to maintain the collections. Our Genomic Resources Collection has benefitted greatly from the guidance from NSRL faculty and staff. We have adopted improved policies and practices that originated at the NSRL and I feel like they are open and willing to share new information and new practices as technology changes and the way that researchers use the collection changes. The NSRL stands out as a leader in the field with respect to development of policies and practices involving Genomic Resources.

As with the NSRL, our natural history collection at Angelo State University (ASNHC) has been an integral part of our teaching and training of students in biology and the biodiversity sciences. Students and researchers benefit from the availability of specimens and tissues in the ASNHC for their research projects. At the global scale, maintaining biodiversity collections for future

generations is important so that we have a documented collection of the life forms on the planet and a reference collection for comparison as the world changes. It is difficult to imagine the discoveries left to make, not only with respect to the anatomy and genetics of the specimen itself, but also the microbes and possible parasites that have been preserved with the specimen. Natural history collections are important resources for these types of studies.

Loren K. Ammerman, PhD
C. J. Davidson "Red" University
Professor of Biology
Curator of Genomic Resources
Angelo State Natural History Collection

I received my Ph.D. in the Department of Biological Sciences at Texas Tech University, studying under Dr. Robert Baker, in 1976. My graduate work at Texas Tech focused on chromosomal evolution in vespertilionid bats. During the time I spent at Tech, I made extensive use of the mammal and herp collections. I deposited the voucher specimens from my dissertation in the mammal collection and I deposited vouchers of studies I conducted on herps, mainly turtles, in the herpetology collection. I contributed frozen tissues and cell lines from my work to the informal frozen tissue collection in Dr. Baker's lab, which were later incorporated into the NSRL's frozen tissue collection. I have made use of the NSRL collections down through the years, mainly as a result of my long-term collaborations with Baker on bat systematics and chromosome evolution. But I think my most important contribution to the NSRL is that the current curator of genetic resources, Dr. Caleb Phillips, was my doctoral student at Purdue University. For all these reasons, I feel a close connection to the NSRL, the Museum, and Texas Tech University.

The NSRL represents a priceless resource for teaching and research. It is difficult to overstate its value to the university and the State of Texas. The collections and all associated with them played an important role in my graduate education and clearly had a profound impact on my career and those of my students. Since my time there, the NSRL and the Museum have grown in stature to where, at least in mammalogy, they are one of the top 3 research collections in the country (in my estimation). The same can be said for so many other former students of the mammalogy program and more generally, for the students in all areas of the natural sciences. I think of the NSRL as being at the base of the very large natural sciences research program, which is one of Tech's strongest programs. It has contributed significantly to the steady growth in size and increase in academic stature that Tech has enjoyed since I was there.

Let me comment now about the significance of the NSRL to fundamental research and to society. Natural science collections serve as the repositories of specimens used for a wide range of research, and the NSRL is the most important facility in Texas and one of the most important in the country. Notwithstanding the fact that such collections have existed for a few hundred years, their value has only increased with time and presently that value is increasing rapidly because of the pace of growth of technology. We are now well into the era of genomics in biology, a field that is moving so fast it is outstripping even the pace of advancement of computer technology. Already, the gold standard in genomics is a chromosome level assembly. Such accurate genome sequences allow the reconstruction of individual chromosomes, and the entire karyotype. The information contained in such a genome sequence is staggering. As Blaxter et al. (2022, PNAS 119:4) describe it: "The history of life and the code for the working parts of cells and systems are written in the genome." In their paper, Blaxter et al. describe the Earth BioGenome Project, which proposes to sequence the genomes of all named species of eukaryotes (about 2 million). The data generated by this program will contribute to addressing the grand environmental challenges of our times, such as climate change and biodiversity loss. But other areas will benefit as well, including medicine, agriculture, materials sciences, etc. But the question immediately arises, where will they get the samples to sequence the genomes of all named eukaryotes? And thus, what will be the ultimate sources of the beneficial discoveries made from such a historic program? The most important sources will clearly be the natural history collections that exist in our museums, university departments, and research facilities. And, as I stated previously, the most important of these in Texas and one of the most important in the country is the NSRL.

John W. Bickham, PhD
Professor Emeritus
Department of Ecology and
Conservation Biology
Texas A&M University

My relationship with the NSRL began as an undergraduate student at TTU, taking classes from distinguished scientists at the NSRL. Later, as a faculty member in the Department of Range and Wildlife Management, I had the great privilege of working with esteemed scientists at the NSRL. These include Drs. Robert Bradley, Robert J. Baker, J. Knox Jones Jr., Robert L. Packard, and David J. Schmidly. To my knowledge and experience, no finer body of natural resource specialists has ever been assembled. Texas Tech University and our natural world is better off because they poured their life's work into the NSRL.

Fred C. Bryant, PhD
Director Emeritus
Caesar Kleberg Wildlife Research Institute
Texas A&M University-Kingsville

The Natural Science Research Lab at the Museum of Texas Tech University has evolved into a premier natural history museum that has supported many scientific endeavors over the past 50 years. I first visited the collections of TTU some 40 years ago, and over the course of my career, this primary biodiversity infrastructure has provided critical sampling and data for numerous molecular DNA studies by graduate and undergraduate students and postdoctoral associates in my lab, in numerous other labs around the United States and around the world. The NSRL is truly a world-class research and teaching facility that serves as a testament to the visionary support of TTU faculty and leadership. The NSRL continues to thrive and shine a bright positive light on Lubbock, Texas and beyond as an example of how long-term commitment to building biodiversity infrastructure can lead to fundamentally new insights in a diverse arena of scientific endeavors. The value (and role) of these collections will be magnified in coming decades as our planet experiences changing environmental conditions, loss of biodiversity, emergent zoonotic pathogens, increasing pollutants, invasive species, and a host of other complex issues of great relevance to society. Congratulations on your 50 th anniversary!

Joseph Cook, PhD
Curator of Mammals
Museum of Southwestern Biology
Distinguished Professor of Biology
University of New Mexico, Albuquerque

I am recently retired as a Professor of Biology, having taught, conducted research, and curated a collection of mammals for the last 34 years at Angelo State University. After completing my B.S. degree at Ohio State University, I began graduate school at the brand new program in Museum Science at Texas Tech University in 1974. That program introduced me to the NSRL collections of mammals and birds and gave me my first experience working in a research collection. I cleaned skeletal material in the mammal collection, acted as the Graduate Curatorial Assistant in the ornithology collection, and deposited mammal specimens from my graduate research at the NSRL. Those experiences and the classes in museum science set in motion my pursuit of a Ph.D. and an academic career that spanned 40 years.

I will always be grateful for the opportunities presented to me at the NSRL and by my mentor at the time, Dr. Hugh Genoways. Since accepting the position at Angelo State in 1988, I have interacted with colleagues at the NSRL, co-published research with them, utilized and published research in the NSRL publications series, Occasional Papers, and I am currently a Research Associate of the museum. Obviously, the NSRL has had a major impact on my life and the lives of thousands of others. There is no question that the positive contributions of the NSRL to education and research within the biological community, both in the United States and internationally, have been and continue to be immense.

Robert Dowler, PhD
Professor of Biology (retired)
Curator of Mammals (retired)
Angelo State University

As the current Collection Manager of Mammals at the Field Museum of Natural History in Chicago, I use my experiences as a graduate student at Texas Tech University working in the NSRL on a nearly daily basis. In fact, the ability to study at a university with such a large and important natural history collection was fundamental to my career path and is a major factor in determining the kind of scientist I am today. Although often viewed as extramural to university priorities, for myself and many of my fellow graduate students the NSRL was VITAL to our development as professional biologists. Through field trips and support from collection staff at the NSRL, I was able to learn the entire process of specimen acquisition, the field-to-drawer process so eloquently outlined by NSRL scientists, as well as the value such collections hold for public engagement, policy development, and protecting human health.

Adam Ferguson, PhD
Collection Manager
Field Museum of Natural History

I am a designer with a childhood passion for nature, and more recently an interest in the world of bugs, which I developed a few years ago when I started using BugGuide and iNaturalist and interacting with professional entomologists. A year ago, Dr. Scott Longing (Entomologist, Department of Plant and Soil Science) suggested that I visit the NSRL Invertebrate Zoology Collection, a true hidden gem within the TTU campus.

Dr. Girón, the Acting Collections Manager, gave me a guided tour of the collection. Noticing my excitement to see some amazing specimens, she invited me to volunteer, which I enthusiastically agreed to. Having no background in the field, she has been providing me with regular training. I have been identifying

specimens and digitizing the syrphid collection since January 2022. Recently, I attended the Entomological Collection Network annual conference.

Volunteering at the NSRL has allowed me to learn a tremendous amount about entomology and the management of natural history collections. It also has encouraged me to become more active helping the iNaturalist community to identify hoverflies. Recently, my husband and I made a financial contribution to the NSRL's Fund for Excellence to provide support for the Invertebrate Zoology Collection, which contributes through curation and research to a better understanding of the challenges biodiversity is presently facing and the solutions to face them.

Catherine C. Galley
Current NSRL Volunteer

In the beginning, there was only the main museum building at 4th and Indiana in Lubbock. The Natural Science Research Laboratory was only a set of architectural plans drawn up by Drs. J. Knox Jones, Jr., Robert J. Baker, Robert L. Packard, and Dilford C. Carter, but not long after my arrival at TTU in 1971, the first phase of the construction of the NSRL was underway. When the Department of Biological Sciences was moved from the Science Building facing Memorial Circle to the new Biological Sciences building, the research collections were moved to a nice large room in the basement of the new Museum building. Eventually, faculty and students with interests in and using the collections had offices in nearby areas of the basement of the museum. These were acceptable facilities, as long as one did not mind not seeing the sun all day. I was one of the first people to move into these offices as a post-doc student of Knox Jones. I was eventually appointed as the Curator for the collection of mammals and as a faculty member in the new Museum Science Program.

In 1973, when construction of the NSRL was completed, we took two days to move the mammal research collections from the basement of the main Museum building to the second floor of the newly completed building. The hurdle that had to be overcome was that the elevator in the new building had not been installed. This meant that muscle power was needed to carry the museum cases one at a time up the first flight of stairs, then hand them over the hand rail to a second team of 4 people to carry them to the top of the second flight of stairs. This took time and human strength but was completed in good time because of a willing and able cadre of faculty, and graduate and undergraduate students. At that point, the NSRL housed a good regional collection of mammals focused primarily on West Texas and immediately adjacent areas. There was no genetic resources collection because no one was doing this work. From these humble beginnings, the NSRL's mammal collection now houses more than 156,000 voucher specimens, and continues to expand in size and in taxonomic and geographic diversity and the Robert J. Baker Genetic Resources Collection is a biological archive of more than 470,000 genetic samples. These samples were taken from >100,000 individual mammals.

Robert Baker and I had the first two major research projects based from the NSRL. One was to study the mammals of the newly established Guadalupe Mountains National Park in West Texas funded by the National Park Service. The other research was funded by the National Science Foundation to survey the genetics of bats in the West Indies. The first project resulted in a large collections of mammals that formed the basis of our contribution to the major volume that we edited: *Biological Investigations in the Guadalupe Mountains National Park, Texas* (Hugh H. Genoways and Robert J. Baker, eds.), 1979, Proceedings and Transactions Series, National Park Service, 4:xvii + 1-422.

Our initial trip to the West Indies in 1974 also marked the true beginning of the Genetic Resources Collection, because it was the first major research effort when we carried a dewar of liquid nitrogen to the islands of Jamaica, Guadeloupe, Trinidad, Puerto Rico, and Hispaniola. Tissue samples were taken from every bat that we captured, and the bats were prepared to serve as vouchers for the tissue materials. The continuation of this work formed a major portion of Robert's and my research for the remainder of our careers. My last trip to the Caribbean was in 2009—all specimens and tissue samples from that trip were deposited in the collections of the NSRL, as were those from all of my other work in the West Indies after I left TTU in 1976. At least 60 of my publications on Caribbean bats were based on material archived in the collections of the NSRL.

Robert Baker and I also cooperated on research projects on the systematics and genetics of mammals in Suriname in northeastern South America. Many of the sites that were visited and sampled have been altered forever by deforestation. What will be known about the biodiversity of the mammals at this critical juncture of the Amazonian rainforest and the ancient tepuis of the Guianan Shield resides in the museum collection of specimens and tissue samples housed in the NSRL. About 30 of my publications resulted from this material. The two Roberts (Baker and Bradley) and I shared a passion for pocket gophers. We completed several papers on these critters from Texas, New Mexico, and Nebraska and all of the material safely resides in the NSRL.

I would estimate that I was a member of field parties that resulted in between 10,000 to 15,000 specimens and tissue samples in the NSRL holdings. To me, this means that TTU and the NSRL hold a significant part of my career in trust.

Why do we need to keep all of these specimens and tissues now that the research is done? They cost a lot of money to maintain and take up a lot of valuable space. Why not just give them away or simply dump them? Many times, museum research collections are compared to a library when trying to explain their value and importance. I find them to be a strange kind of library and to be far more valuable. This would be a library where when one opened the books, they would find that part of the book has been printed, but also many of pages would be blank. Both parts of such a book are valuable to science. The printed portions would represent research completed and published. One of the basic tenets of science is that all research must be able to be repeated to verify it validity. The specimens in the collection "vouch" [assert or confirm a result] for the validity of previous research. This is why I say that TTU holds my specimens in trust. The loss of these specimens would bring the validity of my research into question. To carry the library analogy one step further, this would be like bookworms getting into a library and destroying the printed pages.

The blank pages in the book would represent the research that remains to be done, because as those of us doing research in biodiversity and genetics know, the research is never done. There are always new questions being asked, where the original material must be queried once again. Probably the must recent example was when it was believed that bats were involved in the transfer of COVID-19 to humans. The genetic resources collections of mammals around the world saw a leap in their use that still has not subsided. There have been schemes over the years, and there is even one around today, that proposed to do high-resolution 3-D images of mammal specimens, store the information in a computer, and dispose of the collections. How would one go about extracting DNA from these 3-D images? Museum specimens, including some that are a couple of hundred years old, are being sampled for crusties and small pieces of skin that contain DNA. There are thousands of specimens to be sampled, and unknown numbers of research projects to conducted, because the original material is still available. Museum skin preparation of mammals have been interrogated for environmental contaminates that are preserved in the hairs themselves. There are very recent discussions of gaining deep-time data on climate change, using high-tech resonating techniques on hairs from older specimens. Again, only the actual specimens can be surveyed for such information.

TTU has invested heavily in the NSRL, including a new major addition to the building in 2005. With funds from the National Science Foundation, the NSRL now has state of the art vapor-phase liquid nitrogen freezers. The research collections have also attracted support from the National Science Foundation for their care and maintenance. Clearly, the research community, as demonstrated by this support, has recognized these collections as a nationally important resource. The combination of the mammal research collection and the genetic research collection at TTU are unparalleled nationally and internationally. These resources will serve students and faculty researcher with interests in biodiversity and mammalian genetics for a generation. However, for the collections to realize their full potential, it is imperative that faculty members that perform these types of research remain in charge of these collections. They will attract the high quality students and provide the necessary leadership for growth of the collections and their maintenance.

Hugh H. Genoways, PhD
Emeritus Professor
University of Nebraska State Museum
Lincoln, NE

My history with the NSRL and its collections (primarily the Collection of Recent Mammals) officially began in 1989, when I was accepted into the Graduate Program of the Department of Biology as a Ph.D. student. Under the tutelage of Drs. Robert Baker, J. Knox Jones, Jr., and Clyde Jones (joint curators of the Mammal Collection at the time) I began learning the process of specimen preparations, cataloging and installing specimens in the mammal collection, pest control measures for Natural History Collections, and many other aspects involving natural history collection management. For most of my time while a graduate student at Texas Tech, I also worked with Steven Williams (then the Collections Manager for the NSRL).

My dissertation work was on the distribution and biogeographic relationships of the mammals of the Edwards Plateau region of Texas. It was definitely a field-based study and involved extensive field-based survey work, mammal observations, and voucher specimen collection from this region of Texas. As a graduate student of the Drs. Jones and Baker, I deposited approximately 1,000 mammalian voucher specimens from the Edwards Plateau (and other areas of Texas and New Mexico during my graduate career) into the Mammal Collection of the NSRL. In fact my Dissertation work was largely based upon these survey/field work activities and analyses of existing specimens in the NSRL collection and other major Natural History Collections of Universities in Texas (Angelo State University, Midwestern State University, University of Texas, Austin, Baylor University, West Texas A&M University, Canyon, and Texas A&M University, College Station).

Other research studies during my time as a student at TTU wherein the NSRL resources were intimately involved included mammalian surveys for the City of Lubbock, Texas Parks and Wildlife Department, and U.S. Fish and Wildlife Service at locations such as the now Lake Allan Henry Reservoir site, Big Bend Ranch State Natural Area, Lake Meredith, and the Rosillas Mountains of Big Bend National Park.

After graduation from Texas Tech and accepting a teaching position at Laredo College, I continued to work with my major professors, and others, at Texas Tech, both depositing additional voucher specimens of mammals and borrowing specimens through their loan program. Further, by assuming the burden of specimen accession and curation, the Museum and NSRL tremendously reduce the time, effort, cost, and even worries that would be the responsibilities of many individual researchers and other, much smaller, institutions, such as mine of Laredo College.

As an example of my NSRL-based research, I borrowed a critical specimen of *Mephitis macroura* (the Hooded Skunk) from the Davis Mountains of Texas for re-examination and cranial measurements. This allowed myself and colleagues to complete a brief research study and paper on the species, which was subsequently published within a volume of the *Special Publications* series. Collaboration and access to the NSRL and its resources also has resulted in completion of other research works and studies of species relationships and biogeography of Texas mammals that I and other colleagues have undertaken during my professional career. A few examples include a study of intraspecific variation in species of pocket mice (*Chaetodipus sp.*); a morphometric variation study of pocket gophers; and morphometric studies of the Prairie Vole (*Microtus ochrogaster*) and Harvest Mice (*Reithrodontomys sp.*). The NSRL and its natural history collections have been central in these research pursuits.

Of my approximately 60 published research work and professional reports, almost half (28) are the result of NSRL based research and/or field work activities resulting in NSRL accession of mammalian voucher specimens. I have published the results of my research studies in both the *Occasional Papers* and the *Special Publications* series of the Museum of Texas Tech University and the NSRL. In my opinion, these publication outlets are indispensable for dissemination of field-based, natural history research on mammals and many other taxa within Texas and the United States and, indeed, even various taxa of international origins and distribution as well. The Museum and NSRL have provided publication outlets for almost every taxa of living organisms and, as such, these outlets and the parent natural history collections are of inestimable value to present day and future researchers in the dissemination of this knowledge.

As mentioned, while a student at TTU, I greatly increased my knowledge of fieldwork requirements, various methods of voucher specimen preparation of mammals and frozen tissues, and methods and procedures involved in specimen accession and curation of a natural history collection due to my affiliation with the NSRL and its curators and staff. In turn, these experiences helped me tremendously when, later in my career, I was involved in the planning, construction, and opening of the Lamar Bruni Vergara Environmental Science Center (LBVESC) on the Campus of Laredo College. If fact, I was able to obtain some critical specimen cases when the NSRL updated and replaced many of their older, wooden specimen cases in the Mammal Collection. Those kindly donated specimen cases have since been instrumental in housing specimens for educational and display purposes at the LBVESC in Laredo, Texas. I would summarize by saying that, without my involvement with the NSRL collections and incidental training by its former curators, I would not have been nearly as well-prepared and comfortable in the performance of tasks and job duties which I incurred during my later professional career. Also, I would like to say that the time and activities related to the NSRL helped mold me into a much better researcher and teacher than I would have been had I not had these opportunities while at Texas Tech.

Natural history collections contribute to their respective universities by serving as the basis for many research studies of undergraduate and graduate students. As in my own graduate research, natural history collections frequently are critical in successful study and completion of undergraduate research studies, Masters theses, and Ph.D. dissertations. One of the potential benefits of natural history collections is that they may allow students to complete research studies and/or part of their degree requirements while primarily studying and residing at their respective institutions. Because many or most of the critical voucher specimens may be already at their institution, there is no (or little) need for a student to incur additional expenses for travel and fieldwork. This saves students tremendous amounts of money and time in completion of their academic goals and pursuits and, hence, benefits both the students and the universities. From a personal perspective, my particular research and studies while at Texas Tech would have been impossible without the NSRL and its natural history collections. I am forever grateful to the University, the Museum, and Texas Tech for those resources and their role in my education.

The value of natural history collections to present-day and future research and studies that may aid science and society is literally impossible to accurately calculate or predict. An example of this would be the tremendous increase in knowledge and applications related to molecular biology in recent years. Long ago, or at least

it seems that way, when I first began graduate studies at Texas Tech University, one of the 'hottest areas' of study in biological sciences was still differential banding studies of chromosomes and karyotyping. Since that time, DNA sequencing, genetic engineering, and many other types and applications of what we called molecular biology are now commonplace. The NSRL has played a major role in this research since the beginning of its "Frozen Tissues Collection," as it was called when I was a graduate student.

Related to this topic and aspect of natural history collections, colleagues and myself recently completed and published a 'past and present' genetically-based study of variation within populations of the Texas Kangaroo Rat (*Dipodomys elator*), which is a monotypic, threatened species in Texas. Because this little mammal is threatened, excessive handling and collection of traditional specimens is very limited. Our study was completed because we were able to extract sufficient samples of DNA from hair follicles of some living Texas Kangaroo Rats (without harming them) but also because DNA was successfully extracted from the hair follicles obtained from museum specimens housed in the NSRL and other natural history collections. Therefore, these types of collections also provide opportunities to study threatened or endangered species; opportunities which would not otherwise exist. Finally, considering the advancing state of scientific knowledge and technologies, who knows what may be possible to science and society if these natural history collections are well-maintained, cherished, and preserved by their institutions and, as well, by the informed public!

To conclude, in my case, the NSRL and Museum of Texas Tech University had a central role in my graduate education and the attainment of my Ph.D. in Zoology. Without the NSRL and its collection of Recent Mammals I would never have been able to successfully complete my dissertation studies (and other related research as well). My graduate student office was located within the NSRL and I spent a great deal of my time therein while at Texas Tech. It was a nice quiet place and even the outside grounds, which at that time included a small prairie dog town, ground squirrels, and burrowing owls, provided me with much enjoyment and peace whenever I felt the need to "unwind and air-out" from other activities. I simply cannot imagine a Texas Tech without the Museum and the Natural Science Research Laboratory!

Jim Goetze, PhD
Professor of Biology (Retired)
Chair, Natural Sciences Department (Retired)
Laredo College
Laredo, Texas

I am a volunteer in the Bird Collection (my degree is in Entomology and Applied Ecology). I retired from the Delaware Museum of Natural History after 31 years managing the bird collection and library. My wife, Sally Y. Shelton, left the Smithsonian Institution to be the Associate Director of the Museum of Geology and Paleontology Research Laboratory at the South Dakota School of Mines, where for twelve years I volunteered in the paleontology collections and the campus library. When she left the SDSM to be the Associate Professor of Practice and Assistant Chair, Graduate Program Advisor, of the Heritage and Museum Sciences Program at Museum of the Texas Tech University, it was natural that I should volunteer at the NSRL. As a graduate student, Sally worked at the NSRL for two years.

Upon Sally telling me that there was a long neglected egg collection in the NSRL, I knew that was a perfect fit for me because I had spent much time working in the DMNH egg collection (the second largest in North America). To bring that experience to a collection with the goal of making it usable and available to the research community is invaluable and irresistible. In the course of this effort, I have been fortunate to work with a graduate student who is interested in a career in bird collections. This experience has extended her knowledge of bird collections and collection management beyond what was available prior to my arrival, and this experience is something that few institutions can offer.

Bird egg collections and their associated data are important. They serve as historical documentation of where species bred, when they bred, clutch size, and habitat used. These data can be compared with modern nesting records to detect changes in breeding phenology and distribution. Egg collections have been used to determine the role of environmental pollutants such as DDT (egg shell thinning) and their effect on bird populations (population declines), egg morphology, brood parasite and host egg evolution, and genetic analyses, to mention just a few uses. They remain available for research using technologies such as high-resolution X-ray micro- computed tomography to give the ability to research in 3-dimensional detail. They also provide documentation of human exploration and the history of ornithology and ornithologists.

Given my library experience, I also work on organizing the extensive bird reprint collection in the NSRLs Packard Library. It is fun to come across publications of people I know, as well as those of historical figures who are recognized names in the field.

I enjoy putting my knowledge of bird collections to work at the NSRL and passing it on to interested students, fellow volunteers, and faculty. Talking with students and volunteers in other areas is also rewarding. Recently, I began helping with the ongoing

effort to get the entomology collection data online, taking me back to my days as an entomology student.

Gene K. Hess
Current NSRL Volunteer

My involvement with the NSRL started when I worked on my master's thesis with Dr. David J. Schmidly in 1974. My research was on the taxonomy and chromosomal variation in the plains pocket gopher, Geomys bursarius. Dr. Robert Baker introduced me to the Baker and Williams live gopher trap. Based on the trap he gave me, I started constructing traps that launched my thesis research. I was conducting a detailed morphological analysis along with the chromosomal research, and Dr. Hugh Genoways kindly provided me with specimens collected by R. K. Selander from the University of Texas. Unfortunately, the samples were mummies and required considerable effort to extract the skull and skeleton. After bathing the specimens in oil to entice the dermestid beetles, I finally obtained measurable specimens, and Texas Tech received excellent specimens for their collection. It was a good trade!

In 1977, I started my Ph.D. research with Robert Baker at Texas Tech University. My research pertained to the molecular systematics of New World leaf-nosed bats of the family Phyllostomidae. This research involved collecting expeditions to Mexico, Central America, and South America. We collected specimens for Ira Greenbaum's research on a contact zone involving the bat genus Uroderma, specimens for my research, and those of several other graduate students, including Michael Haiduk, Rebecca Bass, Annette Johnson, and others. We housed all speciments in the Museum at Texas Tech, where Robert Baker was the Curator of Mammals. At that time, Dr. Baker maintained a frozen tissue collection in his laboratory. Therefore, Dr. Baker housed all tissues and cell cultures derived from these specimens in his laboratory.

After graduating from Texas Tech, I had two postdocs, one at Australian University with M. J. D. White and the other at the University of Michigan with Wesley Brown. I became a Curator of Mammals at the Museum of Comparative Zoology at Harvard University and an assistant professor in the Department of Organismic Biology. While at Harvard, I started researching African mole-rats, and two expeditions involved a collaboration with Dr. Duane Schlitter at the Carnegie Museum and graduate students from Texas Tech. Some of the small mammal specimens and tissues went to Texas Tech. During this time at Harvard, I was honored to host Robert Baker on his sole sabbatical from Texas Tech University. We wrote several papers based partially on the material at the Texas Tech Museum.

After a few years at Harvard, I accepted a position in the Department of Wildlife and Fisheries Science at Texas A&M, where I had an additional appointment as Curator of Mammals. I continued researching South America, Europe, Africa, and parts of Mexico and Texas. I accumulated a large tissue collection housed in my laboratory during this time. When I accepted a position at Pepperdine, I housed my tissue collection in ultracold freezers.

When I retired from Pepperdine, I started thinking about where to house my tissues collected over decades. Finding an appropriate place is a difficult proposition because many universities are abandoning their collections, losing materials that are impossible to replace. After visiting the NSRL and seeing the elaborate tissue preservation system, I decided that this was the best place for my collection.

In my estimation, no other facility, especially at a state university, provides state-of-the-art facilities for maintaining irreplaceable natural history collections. I say irreplaceable because many of the places I visited in the Amazon, Kenya, and other regions of the world have lost the habitat necessary to sustain many of the species that my colleagues and I collected. Moreover, many countries, including the United States, have laws that make it challenging to collect specimens. These changes are why collections like those seen at the NSRL are so important. These collections provide a historical perspective on biodiversity. They are helpful for scientists interested in dangerous viral vectors, agricultural pests, invasive species, and changes in diversity in response to landscape and climate change.

I find it prescient that scientists, curators, and administrators at Texas Tech University are willing to commit the time and resources necessary to preserve our national and state heritage. The NSRL represents the future of biodiversity research, and I feel that its importance will only increase as our world and state experience changes that eventually impact all of us.

I am proud to be a contributor to the NSRL. Below are a selection of my publications that were the result of NSRL specimens and tissues.

Book Chapters

1. Baker, R. J., R. L. Honeycutt, and R. A. Bass. 1987. Genetics of vampire bats. Pp. 31-40, in Natural History of Vampire Bats (A. M. Greenhall and U. Schmidt, eds.), C.R.C. Press, Boca Raton, FL, 264 pp. – Editor Reviewed

2. Baker, R. J., R. L. Honeycutt, and R. A. Van Den Bussche. 1991. Examination of monophyly of bats: Restriction mapping of the ribosomal D.N.A. cistron. Pp. 42-53 in Contributions to

mammalogy in honor of Karl F. Koopman (T. Griffiths, ed.), Bulletin of the American Museum of Natural History, no. 206, American Museum of Natural History, New York, NY, 432 pp. – Editor Reviewed

Peer Reviewed Publications

3. Honeycutt, R. L., and D. J. Schmidly. 1979. Chromosomal and morphological variation in the plains pocket gopher, *Geomys bursarius*, in Texas and adjacent states. Occasional Papers, The Museum, Texas Tech University, 58:154.

4. Honeycutt, R. L., R. J. Baker, and H. H. Genoways. 1980. Results of the Alcoa Foundation- Suriname expeditions. III. Chromosomal data for bats (Mammalia: Chiroptera) from Suriname. Annals of Carnegie Museum, 49(16):237250.

5. Baker, R. J., R. L. Honeycutt, M. L. Arnold, V. M. Sarich, and H. H. Genoways. 1981. Electrophoretic and immunological studies on the relationship of the Brachyphyllinae and the Glossophaginae. Journal of Mammalogy 62(4):665672.

6. Honeycutt, R. L., I. F. Greenbaum, R. J. Baker, and V. M. Sarich. 1981. Molecular evolution of vampire bats. Journal of Mammalogy, 62(4):805811.

7. Arnold, M. L., R. L. Honeycutt, R. J. Baker, V. M. Sarich, and J. K. Jones, Jr. 1982. Resolving a phylogeny with multiple data sets: a systematic study of phyllostomoid bats. Occasional Papers, The Museum, Texas Tech University, 77:115.

8. Honeycutt, R. L., and S. L. Williams. 1982. Genic differentiation in pocket gophers of the genus *Pappogeomys*, with comments on intergeneric relationships in the subfamily Geomyinae. Journal of Mammalogy, 63(2):208217.

9. Arnold, M. L., R. J. Baker, and R. L. Honeycutt. 1984. Genic differentiation and phylogenetic relationships within two New World bat genera. Journal of Biochemical Systematics and Ecology, 11(3):295303.

10. Nelson, K., R. J. Baker, and R. L. Honeycutt. 1987. Mitochondrial D.N.A. and protein differentiation between hybridizing cytotypes of the white-footed mouse, *Peromyscus leucopus*. *Evolution*, 41(4):864-872.

11. Honeycutt, R. L., and V. M. Sarich. 1987. Albumin evolution and subfamilial relationships among New World leafnosed bats (family Phyllostomidae). Journal of Mammalogy, 68(3):508-517.

12. Honeycutt, R. L., and V. M. Sarich. 1987. Monophyly and molecular evolution within three phyllostomid bat genera. Journal of Mammalogy, 68(3):518-525.

13. Baker, R.J., C.S. Hood, and R.L. Honeycutt. 1989. Phylogenetic relationships and classification of the higher categories of the New World bat family Phyllostomidae. Systematic Zoology, 38(3):228-238.

14. Hamilton, M., R. L. Honeycutt, and R. J. Baker. 1990. Intragenomic movement, sequence amplification and concerted evolution in satellite D.N.A. in harvest mice, *Reithrodontomys*: Evidence from in situ hybridization. Chromosoma, 99(5):321-329.

15. Jolley, T. W., R. L. Honeycutt, and R. D. Bradley. 2000. Phylogenetic relationships of pocket gophers (genus: *Geomys*) based on the mitochondrial 12 rRNA gene. Journal of Mammalogy 81(4):1025-1034.

16. Bradley, R. D., L.C. Bradley, R. L. Honeycutt, K. A. MacDonald, H. N. Amarilla-Stevens, and R. Stevens. 2020. Nomeclatural, curatorial, and archival best practices for symbiotypes and other type materials in natural history collections. Occasional Papers, Museum of Texas Tech University 366:1-17.

17. Schmidly, D. J., R. L. Honeycutt, R. D. Bradley, and L. C. Bradley. In press. Conclusions. Pp. xx-xx in Taxonomic Catalogs for the Recent Terrestrial Vertebrates (Species and Subspecies) Described Exclusively from Texas (D. J. Schmidly, R. D. Bradley, L. C. Bradley, and Franklin D. Yancey, II, eds.). Special Publications of the Museum, Texas Tech University.

Rodney Honeycutt, PhD
Professor Emeritus
Pepperdine University

The NSRL has been and continues to be of great benefit to me and my research. The collaboration and friendship with other mammalogists at Texas Tech University is wonderful. At a time when the Earth is losing biodiversity, we are also losing the ability to educate people about biodiversity and identify specimens in the wild and in the lab. One reason is that many colleges and universities are no longer interested in maintaining natural history collections that are instrumental in teaching students about biodiversity. The few colleges and universities that do maintain a natural history collection are increasing in size mainly due to incorporation of collections from other schools

and or private holdings. It is a great testament to the NSRL that a fantastic natural history collection is not only maintained, but also strengthened. I am proud of the work of the NSRL and the collaboration with the ACUNHC. Furthermore, I am very grateful for the publication of the *Occasional Papers* series of my research on Ecuadorian mammals. This has been for great benefit to me and my students. Many of the students have gone on to graduate school, and because they already were published as an undergraduate in the *Occasional Papers* series, they were far more competitive with their peers.

Many thanks and congratulations on 50 years!

Tom Lee, PhD
Abilene Christian University

The Natural Science Research Laboratory of Texas Tech University provides essential infrastructure to ensure the preservation of modern voucher specimens (from traditional skins and skeletons to tissue samples and chromosomal preparations, among others). Access to vouchers is a fundamental component to ensure the generation of research on taxonomic diversity, ecology, biogeography, and conservation, as well as to ensure the reproducibility of scientific research and the accumulation of specimens-based knowledge. In the modern era, climate and environmental change result in significant changes in the abundance and distribution of species, including mammals, the focus of my studies.

My research has profited from direct examination of specimens, as well as from tissue loans that contributed important data for my studies. As a researcher, I can attest to the value of these resources and to their availability to the broader scientific community. The NSRL embodies the spirit of individuals like Robert Baker, Robert Bradley, and others that have contributed substantially to the Laboratory's accomplishments and service.

As the current President of the American Society of Mammalogists and regular attendee of the society's annual meetings, I have witnessed countless scientific presentations based, to various extents, on the materials provided by the NSRL. Importantly, these presentations reflect the research activities not only of students and professionals that are based at or directly associated with the NSRL, but also the efforts of those who, like myself, have been able to utilize the resources of the Laboratory.

I am therefore happy to salute the NSRL on the occasion of its 50th birthday. I sincerely hope it continues to impact science for the next 50 years and beyond.

Enrique Lessa, PhD
Department of Ecology and Evolution
University of the Republic
Montevideo, Uruguay

My interaction with the NSRL began in 2013 when my lab received funding to investigate endemic insects occurring in the Monahan's Sandhills in western Texas, including seven beetle species and one Jerusalem cricket endemic to the vegetated and open dunes system. The NSRL expertly facilitated the processing and curating of hundreds of thousands of insect specimens and serves as the main repository of specimens of these endemic insects.

As I became more involved with the Invertebrate Zoology Collection of the NSRL, including writing a recent TPWD grant proposal with Dr. Girón that has been recommended for funding, I was honored to be named a Research Associate of the NSRL. My relationship with the NSRL has been productive in many aspects of my career over the last decade. The NSRL processes and houses important grassland invertebrate biodiversity documented in my research and others research in the region. To date, one Ph.D. student, five undergraduate students, and three undergraduate student interns from Zamorano University working in my laboratory have contributed to work involving the invertebrate collections at the NSRL. Further, I have several manuscripts in preparation and forthcoming that are based on NSRL specimens.

With over 4.5 million specimens, the NSRL serves as a major repository of invertebrate biodiversity, located in a southern latitude and being an anchor to the midwestern US High Plains grasslands region. As such, the NSRL serves this important work and further provides key education in museum science, an important human action given invertebrate declines globally.

The NSRL and invertebrate collection will be instrumental to a new project beginning in winter 2022 involving the digitization of native bee biodiversity from over 17,000 specimens collected across agricultural landscapes of the Southern High Plains. This project will involve cataloging native bee biodiversity, including photographing NSRL specimens and DNA barcoding specialized native bees.

I am grateful to have the NSRL and Dr. Jennifer Giron to help me archive insects for science, education and conservation. Academic natural history collections are deserving of support because they house the biodiversity of nature that, through its discovery and protection, provides the vehicle from which

humans conserve themselves by moving towards Earth- and Bio-centered economies.

Scott Longing, PhD
NSRL Research Associate and
Associate Professor of Entomology
Department of Plant and Soil Science
Texas Tech University

Billy Pat and I have been involved with TTU since the early 1980s working with natural resource students on their doctorate and master's degrees. The NSRL of the Museum played a big part, as we sent large mammal samples directly to them knowing they would be taken care of forever. I had the privilege of going to the field with Dr. Clyde Jones, Dr. Frank Yancey, and Dr. Rick Manning when TPWD acquired the Big Bend Ranch State Park. Dr. Clyde Jones became my mentor and a great friend. Being in the field for over 40 years, I gained a tremendous amount of respect for the NSRL—everything was always conducted above regular standards with professors, curators, and a director that put their heart and soul into the museum collections and their students. Currently our relationship with the NSRL continues and in our opinion, the NSRL, and Museum as a whole, is the best in Texas as well as many other states. This is a direct result of many years of dedication, fieldwork, and integrity. We continue to work with Dr. Robert Bradley and students on wildlife related projects in West Texas. The Museum, the NSRL, and its team continue to set an example that other museums could well learn from.

Billy Pat McKinney, Manager
Bonnie McKinney, Wildlife Coordinator
El Carmen Land & Conservation Co.
Cemex-Texas

I am the Collection Manager in the Section of Mammals at Carnegie Museum of Natural History, where I have worked since September of 1977. For 35+ years, there has been a close connection between Carnegie and the Natural Science Research Laboratory at the Museum of Texas Tech University, in terms of both personnel and collections.

In 1976, Steve Williams left his position at TTU to become the first Collection Manager at Carnegie Museum of Natural History in the Section of Mammals. In 1977, I joined the Section of Mammals and certainly learned from the work that Steve was doing here, as we worked side-by-side in the role of Collection Managers until he left Pittsburgh in 1990. In the years since, I know that the NSRL has continued to uphold the standards for collection care that originated with Steven Williams and the Museum Studies program that began at TTU in the 1970s.

For more than 30 years, Carnegie curators Dr. Hugh Genoways (who was formerly Curator of Mammals at the NSRL from 1972–1976) and Dr. Duane Schlitter collaborated with Dr. Robert Baker and other TTU staff and their graduate students on field work in many locations in the western hemisphere and in Africa. Voucher specimens resulting from those collaborative expeditions often were divided between the NSRL and Carnegie Museum. When tissues were first saved in the early 1980s, Carnegie would often receive most of the vouchers, and the NSRL would take the tissues and just a few representative mammal specimens. Later, when Carnegie obtained ultracold freezers, tissues often were divided between the two institutions.

As a large, private non-profit museum, Carnegie does not have students on-site. However, the graduate and undergraduate students of Robert Baker and other TTU faculty often would borrow voucher specimens from Carnegie for their research. The topics of those studies are too diverse to list! Carnegie curators also served as members of the committees for some TTU graduate students.

In what sometimes seems like a dwindling world of research focused on museum specimens, the *Occasional Papers* and *Special Publications* series of the NSRL provide an important service to the museum and scientific communities by providing an outlet for the results of research being conducted by curators at both the NSRL and Carnegie, often utilizing the specimens and tissues that our two collections have in common.

As a long-time member of the mammal research and collections community, and Past President of the American Society of Mammalogists (ASM), I am aware of the worldwide collections and active research at the NSRL and the many, many students who have gone on to become respected researchers and leaders throughout the mammal research community and the ASM.

The recent pandemic points out usages and applications for voucher specimens and their tissues, which has been obvious to those of us who have worked in the collections for decades but has emerged as a subject that has gained even greater recognition to the general public over the last couple of years. The question of what animal was the carrier for COVID-19 and where did it originate (the lab or in the wild), is one that has been hotly debated, and only a trained mammalogist could explain how the bat species that is thought to be the vector can be identified.

In the most basic sense, natural history collection can bridge the gap between very technical scientific matters and the

mechanisms by which the public can learn about a wide array of topics regarding wild animals, both vertebrates and invertebrates. The very idea that "a bat" is not just one kind of animal but thousands of different species with unique habitats and beneficial uses for humans (such as pollinators, insectivores, etc.), not just the carriers of disease, is among the very first things a student affiliated with a natural history collection learns. That kind of knowledge is disseminated in a multitude of ways to the public—from conversations with family at a holiday gathering (really), to the graduate student or professor who is asked to speak with a journalist to explain in "layman's terms" something complex that can impact the entire world. Three years ago, that would have sounded like an exaggeration.

Suzanne B. McLaren, PhD
Collection Manager, Section of Mammals
Carnegie Museum of Natural History

I have a very long history of association with the NSRL. One of my earliest memories, still in my teens, was meeting one of the founders, Robert Baker, who helped me learn how the NSRL and the mammal collection work. A few years later I requested specimens and then visited the collection. I am in awe of the amazing, far-reaching, deep-diving influence the NSRL has had in the field of mammalian biology. The rate and impact of its publications are very high, and I can only think of a small handful of institutions that are more influential than the NSRL. Thank you for these first five decades of work. You are true champions of natural history and ecology. The world needs more of you.

Rodrigo Medellin, PhD
Institute of Ecology
National Autonomous University of Mexico
National Geographic Explorer-At-Large
CoChair, IUCN Bat Specialist Group

The NSRL and the TTU natural history collections are internationally important resources for the biological sciences. They serve as a beacon to scholars around the world, and foster a community in which TTU is a leading participant. Congratulations on a great half century, and on to the next!

Bruce D. Patterson
Curator Emeritus of Mammals
Field Museum of Natural History

I have been involved one way or another with the development of the NSRL for nearly 60 years, from the time that it was nothing more than a concept to the point where it became one of the most significant and successful academic programs at Texas Tech. During this time, the Mammal Collection and associated Genetic Tissue Collection grew to become some of the most important in the country and world.

I was an undergraduate student in the early 1960s when the idea of building a mammal collection was hatched. Dr. Robert Packard had been hired in the Biology Department in 1962, and he brought with him a small collection of mammals that he had accumulated while at Stephen F. Austin University. I entered Tech in the fall of 1962 and took a class in Vertebrate Zoology that Packard taught. That class, along with Comparative Anatomy, which I also took from Packard, changed my life. I decided that I wanted to be a zoologist and a mammologist and a university professor! Packard took me under his wing and invited me on field trips and offered a chance for me to work on an undergraduate research project studying pocket mice. After graduating with a B.A. degree, I entered the master's program in the Biology program as a student working with Packard. My thesis produced several hundred specimens of Kangaroo Rats that are housed in the mammal collection.

In 1967, I served as a student on the committee that brought Robert Baker to Tech. He and Packard served on my master's committee and together they began a major effort to grow the mammal collection and reputation at the University. This was the genesis of the development of the NSRL, which officially was launched when Knox Jones came to the University as Dean of the Graduate School and VP for Research. This also was when the publication series (*Occasional Papers* and *Special Publications*) were authorized.

After receiving my Ph.D. in 1971, I joined the faculty of the Wildlife and Fisheries Sciences Department at Texas A&M University, in a program that supposedly would be a rival to the NSRL. But because of my previous connection with Packard and Baker, we decided to take a different approach and to cooperate as much as possible. I was invited to be a Research Associate at the NSRL and to publish papers in the two outlets. In return, I sent many of my best master's students to Tech to pursue their Ph.D. degrees with Baker. My students and I published numerous papers in the two publication outlets, and a friendly and cooperative rivalry was born! This turned out to be great fun and highly productive! The A&M and NSRL partnership lasted for 25 years until 1996 when I returned to Tech as a Professor in the Biology Department and as Graduate Dean and VP for Research. In this role, I served on graduate committees, continued to publish papers about Texas mammals (most of which were based on specimens housed in the mammal collection of the NSRL), and I supported the NSRL in every administrative

way possible. In 2002, while serving as President, I published *Texas Natural History A Century of Change* at the Texas Tech Press, and that book was the basis for a major museum exhibit that was hosted at major museums throughout Texas. In 2000, after being named President of the University, I was able to get the Chancellor and Board to commit $5 million for a major expansion of the collection space at the NSRL, to house the ever-growing collection and genetic tissue collection.

During my career, I served as President of 3 major universities (Texas Tech, Oklahoma State, and the University of New Mexico). My experience convinced me that the best way to showcase a university was through excellent academic programs that brought national and international attention through their education, research, and outreach efforts. The NSRL has certainly done this for Texas Tech. The hundreds of undergraduate and graduate students who conducted their research using the collections have found employment at universities, government agencies, and private industry throughout the country and the world. Likewise, the publication series have produced scholarly research from national and internationally recognized scientists. Many exhibits at the Museum have been based on research at the NSRL and have helped educate the public about important scientific and conservation issues. The research grants from faculty and students have been a major part of the growth of Tech into a Research Tier 1 university. Texas Tech is now recognized as one of the leading mammalogy centers in the world, chiefly because of the development of the NSRL and its associated collections. There can be no question that this has helped advance the national and international reputation of the University in a major way!

David J. Schmidly, PhD
Professor Emeritus
Texas Tech University
University of New Mexico

As a retired professor of mathematics I had decided I wanted to learn more about nature. After my wife started volunteering at the NSRL under Dr. Jennifer Girón, who is the Acting Collections Manager of the Invertebrate Zoology Collection, I learned that the NSRL had a large collection of over 35,000 microscope slides of parasites that needed to be digitized. I jumped at the chance to help, since making this unique collection available to researchers around the world is important for human and animal health. Although during my career as a mathematician and computer scientist I had little appreciation of invertebrates, I now have learned that this fascinating group of living creatures is a critical part of the world ecosystem and that diminishing their diversity and numbers has a negative impact on the earth's ability to sustain higher life forms, including humans.

In addition, my wife and I are working with Dr. Robert Bradley, Director of the NSRL, and Scott Trevey, Historic Maintenance Supervisor of Lubbock Lake Landmark, to maintain and enhance the arroyo in front of the Museum's north entrance. We want to enhance the garden to attract a variety of pollinators to allow visitors to see the beautiful native bees, flower flies, and butterflies in addition to the native plants of the Llano Estacado and to provide a best practice model for landscaping. The opportunity to extend our own knowledge and to help others learn to appreciate the incredible beauty of West Texas is exciting and fulfilling.

Carl Seaquist, PhD
Current NSRL Volunteer

I have been involved in mammal collection/preparation for approximately 40 years and have experience as a graduate student and post-doc with several significant mammal collections (Sternberg Museum at Fort Hays State University, Texas A&M Biodiversity Research and Teaching Collections, and the Museum of Natural Science at LSU). My association with the NSRL dates back 35 years to work with Drs. Robert Baker, Clyde Jones, J. Knox Jones, and others on various projects related to mammal collection and preservation of skins/skulls/ancillary materials.

Shortly after starting my current position at Tarleton State University, I quickly realized that the small collection that we had at Tarleton had not been properly curated in the past several years, and that the resources were not available for us to continue to grow the collection. Several years later, I reached out to Robert Bradley at the NSRL to make arrangement for the deposition of future specimens to be accessioned into the TTU collections where they would be: 1) properly curated; 2) readily available to the scientific community as a whole; and 3) associated genetic material would be cataloged and available for loan to other researchers. Dr. Russell Pfau, also at Tarleton, similarly has an agreement that all specimens that he and his students collect for research are assigned a TK number and all tagging, etc., utilizes materials supplied by the NSRL. Once the research is completed, all materials, including frozen tissues, are transferred to TTU for proper accession and curation.

Recently, Dr. Caleb Phillips has submitted a grant that, if funded, would allow for most of the material in our collection to be assimilated into the NSRL collections. I will maintain a small teaching collection, but having the balance of our collections transferred to the NSRL makes scientific sense—placed into

a searchable database that will be accessible to the scientific community at large. In my mind, this is the main value of the NSRL—providing scientific materials for research and inquiry and thus providing a wealth of information or resources to allow scientists to continue to advance our knowledge of the ever- changing biological world around us.

Phil Sudman, PhD
Professor of Biology
Tarleton State University

My name is Cody Thompson, and I am the mammal collections manager at the University of Michigan Museum of Zoology (UMMZ). I am also a member of the research faculty in the UM Department of Ecology and Evolutionary Biology, and I am a research associate at the Natural Science Research Laboratory in the Museum of Texas Tech University.

I received my doctoral degree from TTU in 2013. As a PhD student, I worked in and contributed to the mammal collections at the NSRL. During my dissertation, I not only collected and prepared voucher specimens for my own research, but I also participated in several field trips that generated specimens for other TTU students' projects. These specimens were critical to numerous graduate degrees and resulted in many peer-reviewed publications.

In my current position, my students and I regularly borrow and use NSRL specimens and tissue samples in my research program. I maintain active collaborations with Drs. Robert Bradley and Richard Stevens, including a NSF-funded project on phyllostomid bats. Recently, I participated in a NSRL-led field trip to the Trans-Pecos region of Texas. These specimens are critical for future research and additional collaborative projects with NSRL scientists.

As I continue my career as a mammalogist and museum scientist, I can say with great confidence that the NSRL collections do a fantastic job at training the next generation of collections-based researchers. There are very few programs, especially in mammalogy, that provide students with the collections, resources, and training like the NSRL does. I have tried very hard to emulate the NSRL program at the UMMZ. Being at the number one public research university in the country, I think that says a lot about the quality of what NSRL does as a research institution.

Congratulations on 50 years of excellence!!!

Cody W. Thompson, PhD
Mammal Collections Manager &
Assistant Research Scientist
University of Michigan Museum of Zoology

My connection with the NSRL is based on the fact that the NSRL collections are among the most important for Latin America, containing a large number of specimens and diversity of species from the region. Throughout my professional career, I have worked with the NSRL collections, directly and indirectly, and this relationship has been crucial for my research in northeastern Mexico. The NSRL collections are a vital component for the study of the biodiversity of the Americas.

Specimens and tissues I have borrowed from the NSRL for my research have been used mainly for studies of taxonomy, biodiversity, and conservation of species. In fact, much of the information that has been taken from the collection has been applied to research on rodent species in North America published by the IUCN, which is the international body that dictates protection standards for species worldwide.

Directly or indirectly, 14 of my students, most of them postgraduates, have used NSRL material for their theses research and in the resulting scientific publications.

Several dozen of the articles that I have published in my professional career are based on specimens that are deposited in the NSRL. For this reason, they are an international point of reference for many investigations carried out on mammalian species. In this regard, the collection is a strong international benchmark, since a large number of publications have resulted from these studies have redirected the taxonomy of mammals in Latin America.

I am the founder and manager of one of the most important mammal museums in Latin America (CIB). The CIB has one of the largest collections of tissues in Latin America, and much of the process of building and managing the collections was based on the NSRL model. Since 1991, I have had the opportunity to visit the NSRL and see for myself that the international standards for collections are not only applied and maintained in an appropriate manner and provide an exemplary reference for good collection practices, but many of those standards were developed by the NSRL curators.

In order to conserve species, its basic biology first must be understood. The NSRL has the ideal combination of the two most important elements for biodiversity research: facilities of

international quality, in terms of collections, and an outstanding team of researchers who have been able to make the most of the facility and its collections. Based on specimens from the NSRL, the taxonomy of countless species has been defined. In particular, the studies that have been carried out at the NSRL on various species of bats and rodents have been essential to understanding the current situation and conservation of these two mammalian groups throughout Latin America.

Tissue collections are especially critical as the libraries of biodiversity knowledge for the future, as molecular techniques become more advanced and more effective; even today, the real potential cannot be imagined. They form an infinite database that has many applications, ranging from basic taxonomic studies, to studies in the health sciences and zoonotic diseases.

The ability to borrow specimens and tissues from natural history collections, such as the NSRL, allow for many studies to be conducted without new field collecting, thus saving time, money, and effort by researchers. The collections also allow access to specimens from sites where the species are no longer found due to changes in the environment, species that are considered extinct in nature, or material from remote areas that currently cannot be accessed. The collections of the NSRL are the result of years of work by many biologists, and those collections serve as openly available resources and data that contribute to the training of professionals that are interested in the knowledge of mammal species and that collaborate in the generation of biodiversity knowledge on local, regional, national, and international scales.

It is a fact that biodiversity is declining worldwide, and that natural environments are increasingly modified by humans, directly or indirectly. These modifications are altering the distribution patterns of species, including causing extinctions. Natural history collections such as the NSRL store information about past and present biodiversity, creating awareness of the change that is occurring. These collections allow for the sharing of vital knowledge about diversity and conservation.

Sergio Ticul Álvarez-Castañeda, PhD
Curador de la Colección de Mamíferos
Centro de Investigaciones Biológicas del Noroeste S. C.
Investigador Titular E
Sistema Nacional de Investigadores nivel 3
Premio Nacional de Ecología

My name is Robert Voss, and I am curator of Mammalogy at the American Museum of Natural History and Professor of Comparative Biology at the museum's Richard Gilder Graduate School in New York City. I am also a Research Associate at the NSRL, which I have visited many times to work in the mammal collection, and from which I have often borrowed specimens and tissues for my research. NSRL specimens and their associated DNA sequence data have been crucial for many of my publications over the years, as they have also been for the work of my students and postdocs.

The NSRL is a national treasure. Its collections are an indispensable archive of biodiversity, and it is part of an international network of research collections that support the scholarship of thousands of scientists around the world. These researchers are racing against time to describe and catalog our planet's species and to understand their ecological roles in hundreds of endangered ecosystems. Without these collections, each one with unique strengths, biodiversity research would be impossible.

The NSRL's unique strengths are largely the result of TTU-based researchers and their particular taxonomic and biogeographic interests. For mammals, the NSRL is especially rich in specimens from the southwestern US, Mexico, Central America, and South America. Uniquely, most of these specimens are accompanied by frozen tissues and chromosomal preparations. These are indispensable resources for karyotypic and molecular research that is rapidly changing traditional views about species diversity and phylogenetic relationships.

As importantly, the NSRL is embedded in a university community that has long valued biodiversity research. Such university museums (at TTU, Berkeley, Michigan, Kansas, and Harvard) are where the next generations of biodiversity researchers are trained. They are the future of our science and the hope of our sorry planet. Each one should be cherished and nurtured as unique centers of excellence that set their host universities in a class apart from all the others.

Robert Voss, PhD
Curator of Mammalogy
American Museum of Natural History

I am Curator Emeritus of Mammals at the Smithsonian Institution's National Museum of Natural History. I am a Research Associate of the NSRL, and I started my career at the Smithsonian about the same time that the NSRL was founded. My career was aided in many ways by many scientists associated with the NSRL over the years. I published papers with J. Knox Jones, Dilford Carter, Robert Baker, Hugh Genoways, Steve Williams, Clyde Jones, Jorge Salazar-Bravo, David Schmidly, and many TTU students over the years. I collected various specimens

and tissue samples, mainly from Latin America, that have been deposited in the NSRL collections thanks to joint fieldwork with these colleagues. I studied bats for most of my career and worked intensively on the genus Myotis in recent decades. My students and post-docs made extensive use of specimens and tissues from the NSRL to help resolve evolutionary relationships in this wide-ranging and diverse genus.

I would estimate that more than 20 of my 300 publications were either done in collaboration with NSRL scientists or used NSRL specimens. Several of those were published in the academic publication series of the NSRL. The Occasional Papers and Special Publications of the NSRL are widely used internationally and are respected outlets for papers in evolutionary biology.

The NSRL has been a leader in museum science ever since its founding, and its graduates have gone on to work at major museums worldwide, including my own. Academic natural history collections such as the NSRL are critical components of most major research universities throughout the world. Those repositories and their associated scientists are playing a major role in documenting the effects of key societal issues such as climate change and habitat destruction in today's world. I am proud of my association with the NSRL for the past 50 years and hope that the next 50 will prove equally valuable to Texas Tech University and to research scientists worldwide who will be using the collections.

Don E. Wilson, PhD
Curator Emeritus of Mammals
Smithsonian Institution, National Museum of Natural History

As a graduate student in the Department of Biological Sciences, I have extensively used the Natural Science Research Laboratory (NSRL) and its associated collections (Robert J. Baker Genetic Resources and Mammal Collections) for educational and research purposes over the last seven years. I first gained valuable knowledge on several aspects of museum collections, such as specimen preservation and data entry. I learned what a TK and TTU number is, the associated data that represents an individual, and why data and tissue collection is important.

To put it simply, genetic and genomic research would not be feasible without the NSRL and other similar natural history collections. The collection of specimens and their associated tissues is paramount to any study. First, the actual collection of specimens and their associated tissues provides an understanding of the taxon being examined. This is an aspect of research that is becoming extinct. Second, the generation of DNA or RNA relies on these tissues being publicly available to appropriate scientists. DNA and RNA is not typically outsourced…this genetic material is derived from somewhere and that 'somewhere' is the tissues that are collected and deposited by field researchers. Third, actively collecting specimens and tissues over several decades allows for novel genetic and disease studies. For example, I am currently examining the occurrence of pneumonia in aoudad and bighorn populations in Texas. Although the fieldwork was not specifically for this research, the field researchers took ample tissues of nasal swabs, tonsil swabs, and lung for future studies. Fourth, and perhaps most importantly, collecting one's own specimens gives one an appreciation when requesting a loan for the work that goes into field and curatorial work.

As a senior graduate student in Dr. Bradley's lab, I have mentored 26 undergraduate and six graduate students, all of which have been collaborators on research projects that relied on NSRL specimens and tissues. More than half of these students have conducted fieldwork either during spring or summer break trips, collected their own tissues and prepared museum specimens, and learned genetic laboratory techniques. These students truly have participated in the 'farm-to-table' version of 'fieldwork-to-published research.'

I have seven publications, all of which are the result of NSRL-based research. Two manuscripts were published in the *Occasional Papers* series of the Texas Tech Museum. The *Occasional Papers* and *Special Publication* series are important outlets that allows beginning graduate students to get their feet wet with publishing a manuscript.

My experience as a graduate student has been heavily impacted by the NSRL, for the better. Through formative experiences, such as fieldwork in courses like Field Methods and daily research, I am a perspective candidate for almost any occupation in the research realm of mammalian genetics and disease. In fact, it is the reason why I have been selected for a CDC Viral Hemorrhagic Fevers Virus Host Ecology Fellowship through ORISE. The NSRL and its associated field biologists, genomicists, curators, researchers, and collection managers allow good students and good research to be outstanding. I hope the mission and legacy of the NSRL continues in perpetuity.

Emily Wright
PhD Candidate
Department of Biological Sciences
Texas Tech University

My name is Frank Yancey and I currently am a biology professor at Oakhurst College Center in Central California and a proud

research associate of the Natural Science Research Laboratory. My association with the NSRL began over 30 years ago when I entered into a Ph.D. program at Texas Tech University. I recall clearly the first time I set foot in the NSRL in the summer of 1991. I had just arrived from California and I was there for my initial meeting with Dr. J. Knox Jones, who was to serve as my committee co-chair along with Dr. Clyde Jones. Following the meeting, Knox gave me a general tour of the NSRL and explained that I would be doing my research primarily out of this facility. I could not believe that such a facility existed and that I was going to be so fortunate to have the opportunity to do research there.

Since that initial visit, I have maintained a continuous working relationship with the NSRL. In 1996, I completed my Ph.D. with a dissertation entitled "Diversity, Distribution, and Natural History of the Mammals of Big Bend Ranch State Park, Texas." The majority of the data used in the dissertation came from the collection and preservation of mammal specimens that now are archived in the collection at the NSRL.

Following the completion of my Ph.D., I completed one year of post-doctoral research at the NSRL under the direction of Drs. Robert Bradley and Robert Baker. Throughout the year, I was involved in extensive specimen collection at various Texas Parks and Wildlife facilities across the state, as well as at Fort Bliss Military Reservation in Texas and New Mexico. During this time, I also served as assistant collections manager at the NSRL. After departing Texas Tech 25 years ago for a position in California, I continued to conduct collection-based research out of the NSRL, primarily with Clyde Jones in the Chinati Mountains State Natural Area and Big Bend Ranch State Park, where I continue to do research today. Concurrent with these field-based projects, I completed several research projects on specimens archived at the NSRL.

Over the years I have collected, prepared, and deposited over 3,300 specimens of skins, skulls, and/or vital tissues in the collections at the NSRL, and I continue to deposit specimens associated with current research. My NSRL-based research has resulted in 67 publications, including five as *Special Publications of the Museum* and 15 as *Occasional Papers of the Museum*. These NSRL publication outlets are critical for the dissemination of museum-based research, as there are few such outlets that focus on this type of research.

In conclusion, the enormous impact that the NSRL has had on my research career is impossible to state. More importantly, the specimens housed and curated at this signature facility of Texas Tech University have played an immeasurable role in many critical systematic revisions, conservation studies, and public health investigations. Further, the NSRL has inspired and facilitated the studies of countless biology and museum science students over the years, and, given the proper support, will continue to do so for a long time into the future.

Franklin D. Yancey, III, PhD
Oakhurst College Center
Oakhurst, California

MUSEUM OF TEXAS TECH UNIVERSITY
3301 4TH ST
LUBBOCK, TX 79409