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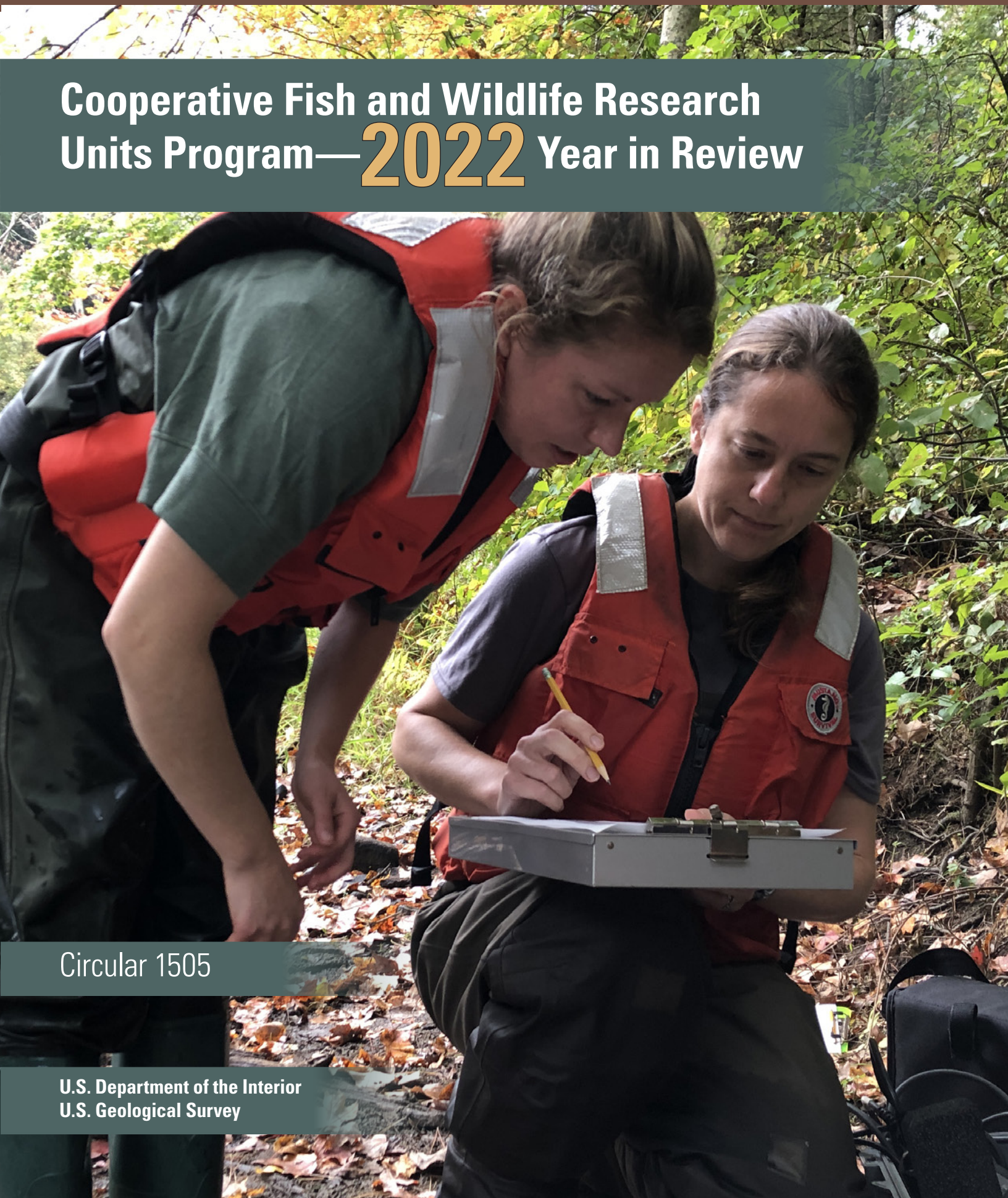
Cooperative Fish and Wildlife Research Units Program—2022 Year in Review



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Front cover. Ayla Skorupa, a graduate student at the University of Massachusetts, reviews field notes on native mussels with Unit Leader, Allison Roy (Massachusetts CRU). Photograph by Naila Moreira.

Inside front cover. American Bison (*Bison bison*) at Rocky Mountain Arsenal National Wildlife Refuge in Colorado. Photograph by Jim Carr, U.S. Fish and Wildlife Service.

Title page. Brown pelican (*Pelecanus occidentalis*). Photograph by Jackie Orsulak, U.S. Fish and Wildlife Service.

Back cover. A plains spotted skunk (*Spilogale interrupta*) doing a handstand. Photograph by Jerry W. Dragoo, used with permission.

Cooperative Fish and Wildlife Research Units Program—2022 Year in Review

By Elise R. Irwin, Donald E. Dennerline, J. Barry Grand, and Jonathan Mawdsley

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U.S. Department of the Interior
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U.S. Geological Survey, Reston, Virginia: 2023

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Contents

Pronghorn (*Antilocapra americana*)

Abbreviations

AFS	American Fisheries Society
ARU	Autonomous Recording Unit
AUL	Assistant Unit Leader
BOR	Bureau of Reclamation
CASC	Climate Adaptation Climate Center
CFD	Chronic Foot Disease
CRU	Cooperative Fish and Wildlife Research Units
CWD	Chronic Wasting Disease
DDCSP	Doris Duke Conservation Scholars Program
DEIA	Diversity, Equity, Inclusion, and Accessibility
DEIC	Diversity, Equity, and Inclusion Committee
DNR	Department of Natural Resources
DOD	Department of Defense
DOI	U.S. Department of the Interior
eDNA	Environmental DNA
ESA	Endangered Species Act
FY	Fiscal Year
GPS	Global Positioning System
GSM	Global System for Mobile Communications
M	million
M.S.	Master of Science degree

MSU	Michigan State University
NDVI	Normalized Difference Vegetation Index
NGO	Non-governmental Organization
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRCS	Natural Resources Conservation Service
Ph.D.	Doctor of Philosophy degree
PIT	Passive Integrated Transponder
PSFC	Prairie Streams and Fishes Collaborative
RAD	Resist-Accept-Direct
RRVNWR	Rappahannock River Valley National Wildlife Refuge
RWO	Research Work Order
SGCN	Species of Greatest Conservation Need
SSA	Species Status Assessment
SWAP	State Wildlife Action Plan
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VOAGL	Voice of America Game Lands
WMI	Wildlife Management Institute

Northern Pintail (*Anas acuta*)

Message from the Chief

This has been another outstanding year for the CRU Program, and I am pleased to provide you with our 2022 Year in Review report. Highlights of this past year include the creation of our 42nd unit at Michigan State University and the completion of hiring activities for 37 new unit scientists in 31 States. In this report, you will learn more about the spectacular accomplishments of our students, research staff, and scientists over the past year. We are pleased to report that we continue to see increases in the number of students enrolled in the program, number of active projects, and number of publications and trainings offered to our partners and collaborators. Our dedicated Diversity, Equity, and Inclusion Committee continues its valuable work to ensure that all members of our CRU family feel welcomed and included. We continue to grow our partnerships with key external collaborators such as WMI, The Wildlife Society, and USFWS. Our university and State cooperators remain steadfast in their commitment of involvement and have embraced the growth of the program, as we fill some long-standing vacancies and add additional units. I am especially proud of the work of our CRU headquarters staff, regional supervisors, and administrative support staff, who have helped coordinate hiring activities behind the scenes. I am grateful for the work of each of our staff scientists, graduate students, and postdoctoral fellows – it is your intellectual curiosity, outstanding critical thinking, dedication to learning and growth, and most importantly, your commitment to collaborative problem-solving with our friends and partners – that truly makes our program a success. It is a great time to be a part of the CRU Program, and I hope that you look forward to learning about our most recent accomplishments throughout this report.

Sincerely,

Jonathan Mawdsley, Ph.D., Chief

Digger Bee (*Anthophorini*)

Special Appreciation

To our friends at the Wildlife Management Institute (WMI), and especially WMI President Steve Williams, who has been a strong ally of and advocate for the Cooperative Fish and Wildlife Research Units (CRU) program for many decades. Steve, himself a product of the unit program, has helped CRU staff and scientists connect effectively with a broad range of natural resource conservation professionals on numerous conservation issues and initiatives over the years. Our congratulations to Steve on his upcoming retirement and our sincere gratitude for his long-term support and commitment to this program. We also appreciate and recognize the work of WMI's Chris Smith, Bill Moritz, Scot Williamson, and Jon Gassett for their hands-on assistance with individual units, and we thank Jennifer Mock Schaeffer for her efforts to help us better understand and meet priority conservation needs at the State and regional levels.

Acknowledgements

Three U.S. Geological Survey (USGS) reviewers (John Thompson, Lianne Ball, and Allie Weill) provided critical feedback on the product and thereby enhanced the report's quality. John Thompson, Dawn Childs, and Brett DeGregorio (USGS) provided text for portions of the document. Tess Gingery provided the scientific and common names review. David Hu and Martha Mather (USGS) authored the Prairie Streams and Fishes Initiative summary. Each project summary was authored by the lead unit scientist(s) and edited for length by the report authors.

Male Mallard (*Anas platyrhynchos*)

Cooperative Fish and Wildlife Research Units Program—2022 Year in Review

By Elise R. Irwin, Donald E. Dennerline, J. Barry Grand, and Jonathan Mawdsley

Cooperative Fish and Wildlife Research Units

Established in 1935, the CRU program is a unique cooperative partnership among State Fish and Wildlife agencies, host universities, WMI, USGS, and the U.S. Fish and Wildlife Service (USFWS). Designed to meet the scientific needs of natural resource management agencies and to produce trained wildlife management professionals, the program has grown from the original 9 wildlife-only units to a program that today includes 42 units located on university campuses in 40 States.

- State fish and wildlife agencies
- Universities
- Wildlife Management Institute
- U.S. Geological Survey
- U.S. Fish and Wildlife Service

Budget

Michigan Unit Added in Fiscal Year 2022!

Fiscal year (FY) 2022 included a budget increase for the fourth year in a row and brought the budget to approximately $26 million (M) (fig. 1). Part of the congressional budget language for this year's increase was to establish a new unit in Michigan. That directive was fulfilled, with the completion of a Cooperative Agreement establishing a new CRU in the State of Michigan (fig. 2). The new Michigan Unit will be based at Michigan State University (MSU) in East Lansing, Michigan. Founding partners include Michigan Department of Natural Resources (DNR), MSU, USFWS, USGS, and WMI. Gratitude is extended to Northeast Regional Supervisor Dr. Cyndy Loftin for her leadership in helping to create this unit. Dan Eichinger and his staff at Michigan DNR, Russ Mason (Michigan DNR and MSU), Charlie Wooley and Craig Czarnecki (USFWS), and Bill Moritz (WMI) are to be commended for their engagement and support for the new unit. This latest addition to the CRU family will build on newly established productive relationships to deliver solutions to problems using sound science in Michigan.

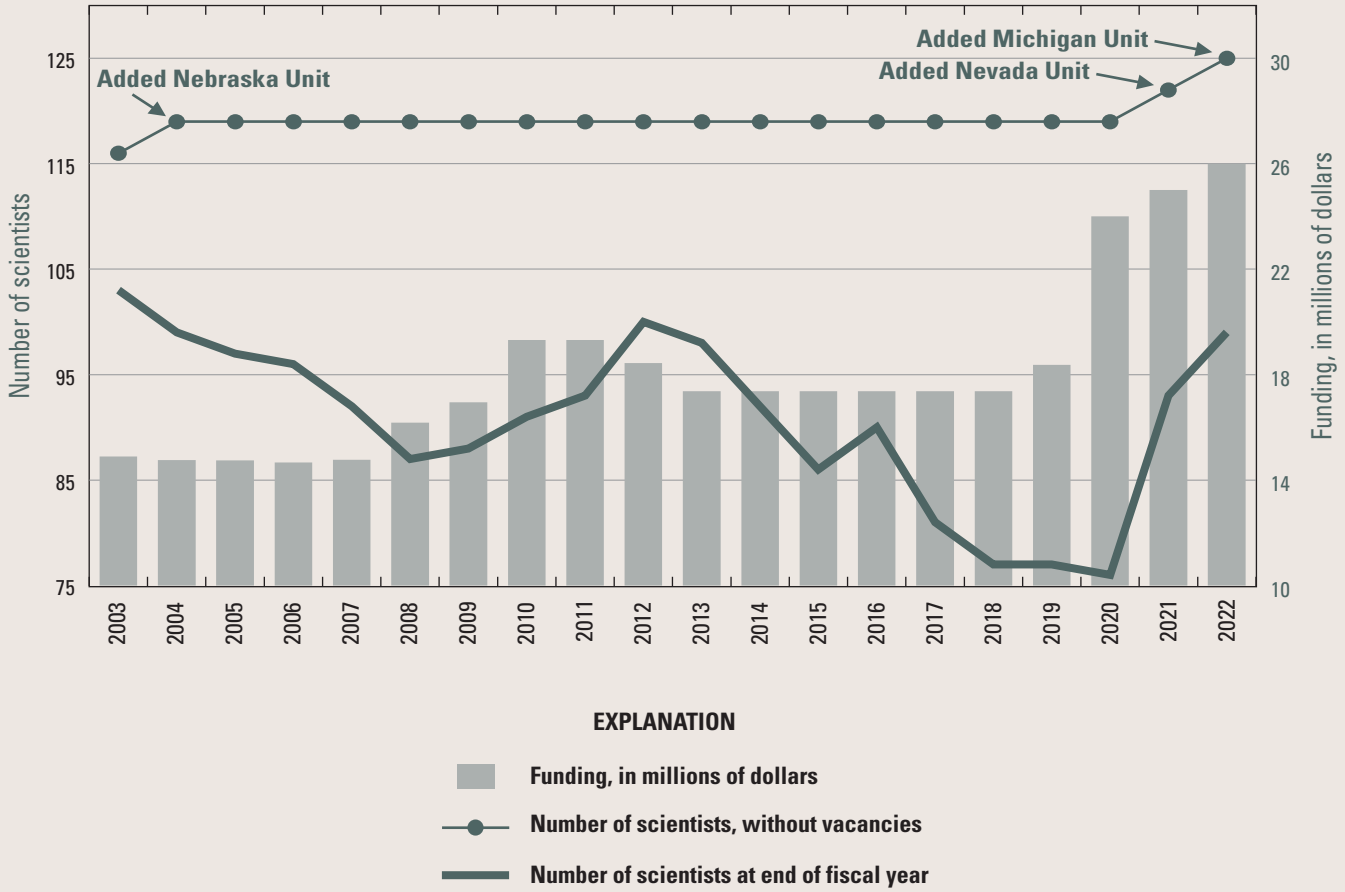


Figure 1. Graph showing budget and staffing data for the U.S. Geological Survey Cooperative Fish and Wildlife Research Units program during fiscal years 2003-2022. Note that the scale of the left y-axis starts at 75 personnel.

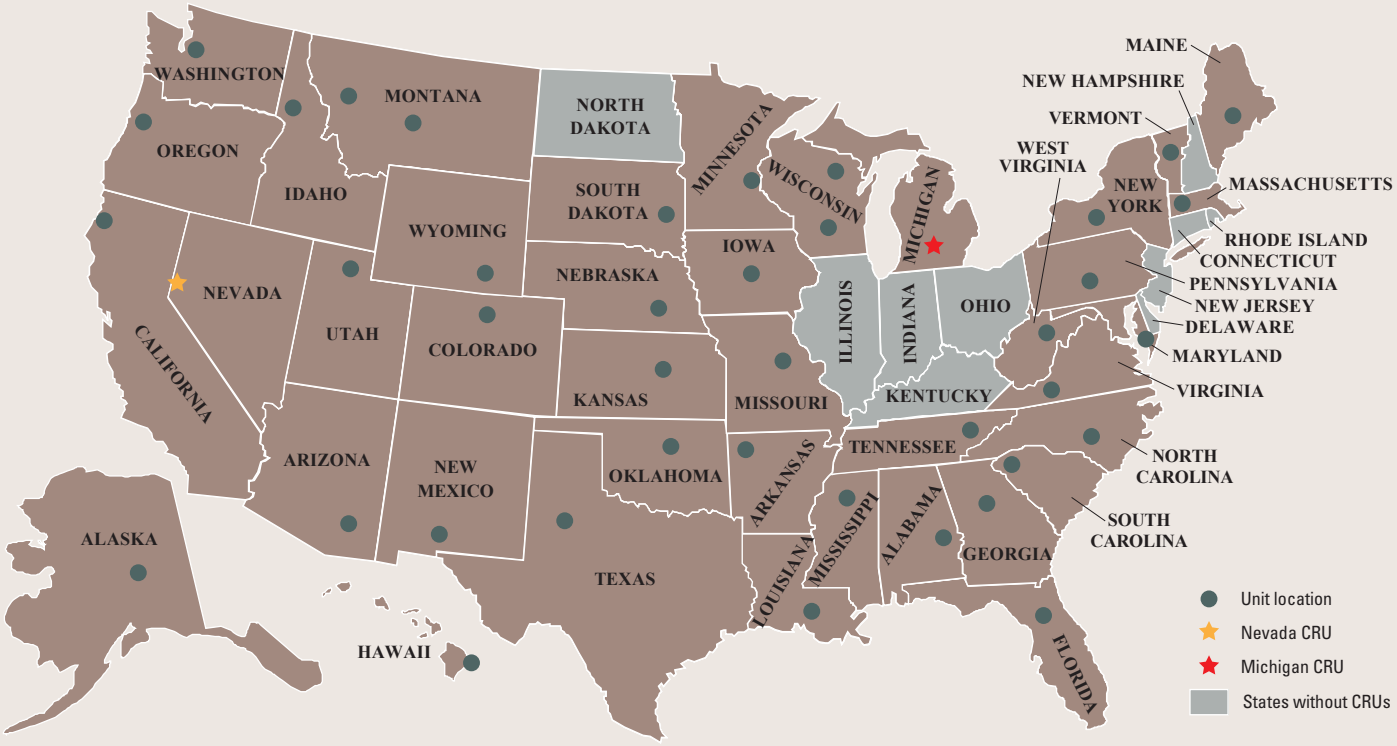


Figure 2. Map of U.S. Geological Survey Cooperative Fish and Wildlife Research Unit (CRU) locations in 40 States, at 42 host universities. Newest CRUs are indicated: Nevada CRU, established in 2021, is noted by a yellow star and Michigan CRU, established in 2022, is noted by a red star.

Staffing

The recent budget increases allowed the CRU to continue to actively fill positions over the past 2 years, with 37 new scientists brought onboard (26 in FY21 and 11 in FY22). However, 27 vacancies remained at the end of the FY22 owing to the loss of 14 scientists (retirements, resignations, death) over the past 2 years, and the addition of 6 new positions at the new units. Hiring actions have been initiated to fill another nine positions, including Unit Leader positions at the new Nevada and Michigan units.

Operational Support

The recent budget increases provided needed operational support to the CRUs, with respect to capital investments for items such as vehicles and safety equipment. This significant financial commitment has been lacking in recent years as a result of an extended period of flat funding during government budget sequestration (2013–18) that resulted in little to no financial support for operational investments. Consequently, operational equipment such as the vehicle fleet continued to age without replacement and the vehicles are now approaching the end of their serviceable life. Under the scenario with 30+ vacancies, the units could be operational with the existing vehicle fleet because demand was down. However, with 37 new scientists recently brought into the program and 27 more yet to come, a significant investment is needed in operational items, such as vehicles, watercraft, all-terrain vehicles, utility terrain vehicles, along with laboratory and safety equipment to support the active and growing field research programs of potentially 60+ new scientists.

How the CRU Works

Mission

The mission of the CRU program has three directives: (1) conduct research to deliver actionable science to cooperating agencies and organizations; (2) develop the natural resource conservation workforce of the future through graduate education; and (3) fulfill the training and technical assistance needs of cooperators.

Research Priorities

Following the original legislation that created the CRU program (Public Law 86–686), all research priorities are set locally at each unit in consultation with Federal and State cooperators. Unit scientists and unit supervisors work with cooperators to help them identify their needs, and unit supervisors ensure that all research conducted is aligned with the USGS mission. Unit scientists, associated faculty, staff and students regularly conduct research projects in coordination with, and to meet the needs of, USGS headquarters, regions, and science centers. See the Notes from the Field section for examples of collaborative work with science centers, States, non-government organizations (NGOs), and other Federal cooperators. Final approval for each project is made by CRU headquarters management (Chief or Deputy Chief) to ensure that projects meet the USGS mission and the Department of Interior (DOI) priorities.

Project Controls

Research Work Orders (RWOs) are the mechanism through which host universities receive Federal financial support to conduct research, as provided for in the 1978 amendment to Public Law 86–686. RWOs are an extension of the Cooperative Agreement establishing each unit. Funds from the USGS, other DOI bureaus, or other Federal agencies are obligated via financial assistance into a RWO and awarded to the host university for a specific research project.

The Deputy Chief ensures that the project meets the requirements for a RWO, including the following (1) the project must be novel research; (2) the project must be consistent with the mission of the USGS and DOI priorities; (3) the project must have an educational component; (4) the budget is complete and appropriate; and (5) no apparent conflicts of interest exist.

Regional Engagement and Coordination

CRU headquarters staff and leadership work closely with key regional partners, including USGS Center Directors, USGS Regional Directors, USGS Ecosystems Mission Area leadership, as well as leadership from other agencies, such as the USFWS. The Chief of the CRU program works closely with USGS Center Directors and USGS Regional Directors on topics of mutual interest. For example, the development of an interagency pollinator science laboratory that engages regional staff, center scientists, and external partners (such as, USFWS, U.S. Department of Agriculture [USDA], the Northeast Association of Fish and Wildlife Agencies, National Park Service [NPS], and the Smithsonian Institution) in research to inform pollinator conservation activities at State and Federal agencies.

Leveraging Resources and Creating Jobs

Through their research programs, CRU scientists create jobs at the host university. Each CRU scientist supports graduate students, postdoctoral, and research technicians, which collectively amounts to approximately 1,000 university positions supported per year. The number of degrees awarded and active students, postdoctoral researchers, and university research staff during FY22 in the CRU program are shown in the infographic below. The CRU program also leverages the contributions of each cooperator, such that Federal salary dollars are matched on a 1:3 basis by State and host university contributions and grant funds. In FY22, the CRU budget of $26M brought in approximately $40M in reimbursable research funds to the host universities, who provided more than $20M through in-kind support (such as, office space or use of university equipment), tuition, and reduced overhead.

52

Graduate degrees awarded (43 M.S. and 9 Ph.D. degrees)

505

Active graduate students (325 M.S. and 180 Ph.D. students

78

Postdoctoral researchers

64

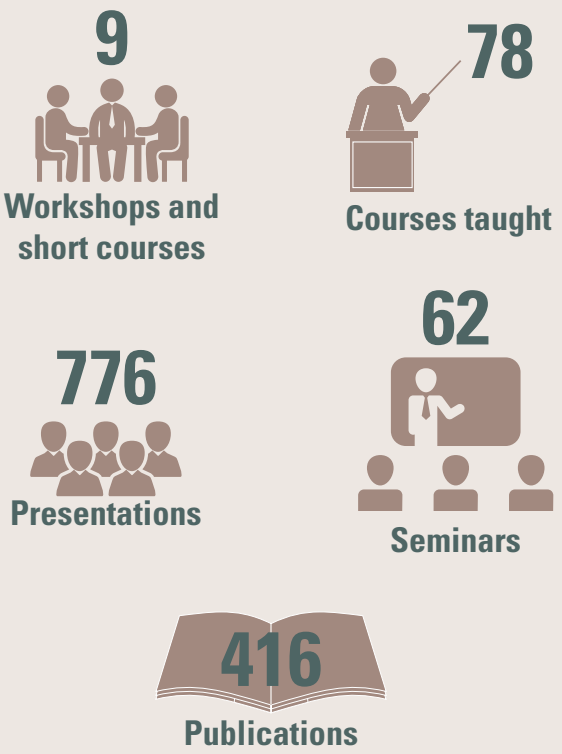
Undergraduate students

279

Active university research staff

Productivity

Scientists and their research staff and students in the CRU program are highly productive, publishing 416 scientific papers in FY22. Papers were published in 175 peer-reviewed journals, ranging from international journals such as *Nature* to regional journals such as *Southwestern Naturalist*. Based on the number of articles per journal, where CRU Scientists and their students and research staff published papers, the top 20 most published-in scientific journals are reported in the table below. Forty percent of all publications were published in these 20 journals in FY22. Five CRU scientists received prestigious awards for their publications. In addition, CRU scientists serve on editorial boards for many journals, lending expertise to scientific review and article selection. More than 78 courses were taught in FY22 at host universities to 1,056 graduate students. In addition, many workshops and short courses were delivered and tailored to cooperators' needs for setting conservation objectives and providing collaborative decision-making tools.



The twenty most published in journals, based on the number of articles per journal, where Cooperative Research Unit scientists and their students and research staff published papers.

Journal	Number of articles
North American Journal of Fisheries Management	28
Global Ecology and Conservation	10
Journal of Fish and Wildlife Management	10
Journal of Wildlife Management	10
Ecology and Evolution	9
Ecosphere	9
Fisheries	8
Ecological Applications	7
Ecological Indicators	7
PLoS ONE	7
River Research and Applications	7
Transactions of the American Fisheries Society	7
Freshwater Science	6
Journal of Environmental Management	6
Journal of Great Lakes Research	6
Wildlife Society Bulletin	6
Canadian Journal of Fisheries and Aquatic Sciences	5
Forest Ecology and Management	5
Frontiers in Ecology and the Environment	5
Science of the Total Environment	5

Awards to Cooperative Research Unit Scientists for excellence in their publication records.

[USFWS, U.S. Fish and Wildlife Service; AFS, American Fisheries Society]

Scientist	Award	Awarding organization
David Andersen	Best Journal Article	The Wildlife Society
David Haukos	Morgart Scientific Publication Award	USFWS
Christina Murphy	Top-cited article	Wiley
Craig Paukert	One of the top 10 percent most downloaded papers in calendar year 2021.	AFS
Lillian Raz	Finalist for the best paper in Functional Ecology by an early-career author	British Ecological Society

Unit scientists garner

$25 million to $40 million

in State and Federal research funding each year

Federal investment supports about

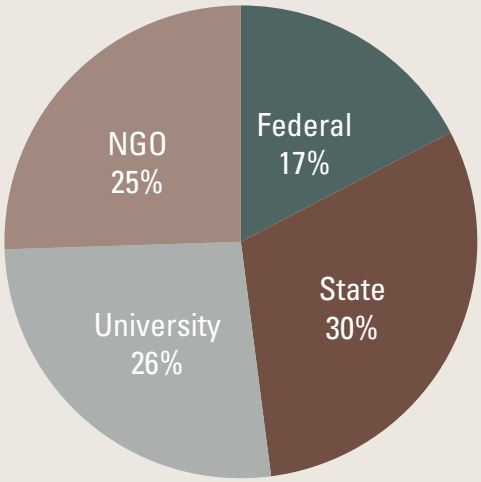
1,100 students and university staff members

annually

Universities provide more than

$20 million

through in-kind support, tuition, and reduced overhead

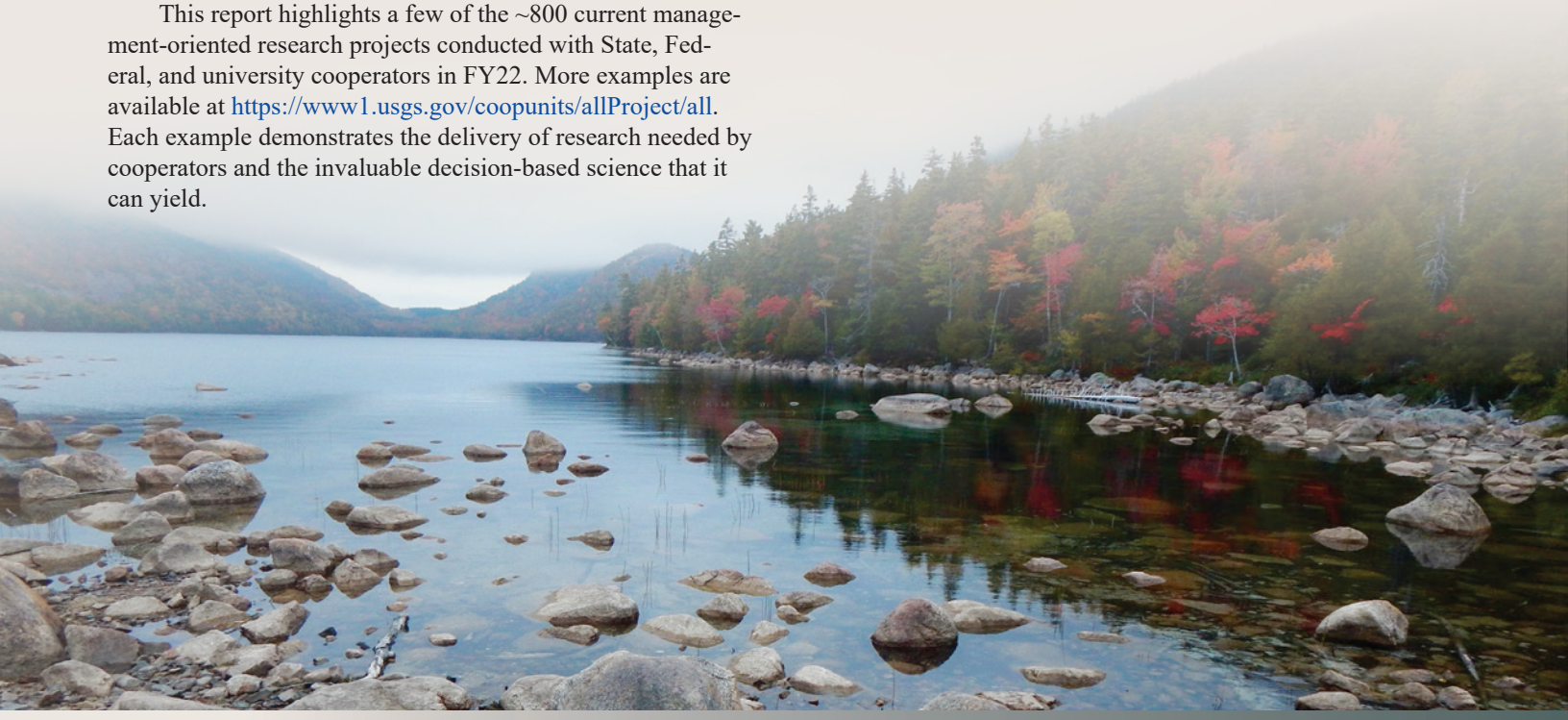


Pie chart showing the types of professional positions obtained by recent graduates who participated in the Cooperative Fish and Wildlife Research Units program. Data are averaged for fiscal years 2012–2021. NGO, nongovernmental organization; %, percent.

Applied Research to Meet Cooperators' Science Needs

The CRU program is a leader in applied research, providing objective science for the management needs of cooperators and informing decision-making. The research priorities for each unit are established locally in consultation with Federal and State cooperators.

This report highlights a few of the ~800 current management-oriented research projects conducted with State, Federal, and university cooperators in FY22. More examples are available at https://www1.usgs.gov/coopunits/allProject/all. Each example demonstrates the delivery of research needed by cooperators and the invaluable decision-based science that it can yield.



Science Themes and Projects

The science themes highlighted in this year's report were based on input from cooperators, scientists, and regional directors. Relevant themes were identified for each project and the primary theme was used to arrange them in the report. Most of the projects described could be categorized into two or more themes. Project descriptions for each CRU, also referred to as a unit, were authored by the lead CRU scientist and accessed through the CRU database. Some descriptions were edited for length and clarity by the report authors.

- Animal Migration
- Invasive Species
- Species of Greatest Conservation Need and Threatened/Endangered Species
- Decision Science or Structured Decision Making
- Wildfire
- Diseases of Fish and Wildlife
- Advanced Technologies
- Grassland Management and Restoration
- Water Allocation, Drought, and Ecological Flows
- Population Monitoring and Advanced Modeling
- Hunting and Fishing

Animal Migration

Many species of animals migrate to conduct or complete critical natural life history activities, such as feeding or mating. Many migrating species also face obstacles to migration along the corridors they travel, such as fences, roads, or dams. CRU scientists are using multiple techniques to study movements of many different species—from butterflies, bats, and birds to bison, salmon, herrings, and bears—to deliver management and conservation relevant data to State and Federal cooperators who manage these species and their habitats, including connectivity of migration corridors.

New Mexico Unit

Identification and characterization of habitat conditions of mule deer (*Odocoileus hemionus*), elk (*Cervus elaphus*), and pronghorn (*Antilocapra americana*) migration routes and stopover locations in northern New Mexico. Migratory hoofed mammals, or ungulate, populations require distinct winter and summer ranges (and resources therein) to fulfill their life history requirements (for example, reproduction), and acquire sufficient nutrition to maintain population vital rates (such as, adult and juvenile survival) that prevent population declines. The New Mexico Unit is identifying and mapping seasonal ranges, migration routes, and stopover locations for mule deer, pronghorn, and elk in northern New Mexico, allowing State and Federal agencies to identify and mitigate potential threats to the persistence of these migration routes. The unit is also assessing habitat characteristics along the migration routes and at stopover locations to allow for more informed management of these migratory populations.

Maine Unit

Passage of adult Atlantic salmon (*Salmo salar*) in the Penobscot River before and after dam removal. The Maine CRU is quantifying migration attributes for endangered Atlantic salmon to inform restoration strategies for the species. The Penobscot River has experienced two main-stem dam removals and other engineering changes, including the installation of a fish lift at Milford Dam (the lowest dam in the system) with hopes of restoring Atlantic salmon. Efforts to restore Atlantic salmon will rely on safe and effective fish passage. The CRU is using acoustic, radio telemetry, and Passive Integrated Transponder (PIT) tag technology to characterize migration patterns and passage efficiency of adult Atlantic salmon. This work in the Penobscot River, Maine, requires effective collaboration with USFWS, National Oceanic and Atmospheric Administration (NOAA), Penobscot Nation, Maine Department of Marine Resources, Brookfield Power, Nature Conservancy, and the Penobscot River Restoration Trust.

Wyoming Unit

How do ungulates learn to migrate? A century-long case study with American bison (*Bison bison*) in Yellowstone National Park. The story of how bison rediscovered their lost migrations over a 100-year period is one of the few examples, worldwide, of ungulates learning to migrate. This Wyoming CRU led project will aim to reconstruct how generations of American bison living in Yellowstone National Park established the migration routes they now use to travel seasonally in and out of Yellowstone National Park. The question of how ungulates learn to migrate is important for modern conservation, and this study will deepen our understanding of what is possible for animals recolonizing a landscape. CRU scientists are analyzing the effect that certain active management techniques, such as hazing (that is, herding bison to keep them in a certain range) have on bison movement at different times in their history. By building a timeline of these events, unit scientists will identify techniques that had lasting effects on bison movements, and those that did not. In addition to historical research, modern Global Positioning System (GPS) collar data and contemporary movements will be analyzed to understand what ranges and movements were possible for bison in the past. Other Wyoming Unit ungulate migration published products are the Wyoming Migration Initiative and the Migration Mapper (https://migrationinitiative.org/content/migration-mapper). This year the Second Volume of the Ungulate Migrations of the Western States (https://pubs.usgs.gov/sir/2022/5008/sir20225008.pdf) was published by the USGS and includes many partners from collaborating universities, NGOs, States, and Federal agencies.

Minnesota Unit

Minnesota trumpeter swan (*Cygnus buccinator*) migration ecology and conservation. The Interior Population of trumpeter swans was re-established through reintroduction efforts beginning in the late 1960s. Since that time, the population has exceeded reintroduction goals and now numbers more than 25,000 individuals. As the population moves from rare to abundant, lack of information regarding basic ecology hinders planning for population management. The unit is marking trumpeter swans with GPS- Global System for Mobile Communications (GSM) transmitters to: (1) evaluate year-round swan movements; (2) determine whether and where swans make molt migrations; (3) evaluate year-round habitat use and selection patterns of swans; and (4) evaluate survival and mortality rates of swans. The project is evaluating the current population genetic structure and assessing environmental lead exposure. Partners include the University of Minnesota, USFWS, Canadian Wildlife Service, Manitoba Conservation, Minnesota DNR, Wisconsin DNR, Michigan DNR, Iowa DNR, Great Lakes Indian Fish and Wildlife Commission, and the Trumpeter Swan Society.

Invasive Species

Invasive species are those found outside their native geographic range that cause negative economic or environmental harm to human, animal, or plant health. CRUs provide critical information to agencies charged with managing invasive species and controlling their impacts on native species or recreational resources. Research conducted by CRU scientists includes the development of innovative techniques to determine the abundance and distribution of invasive species, as well as projects to determine the efficacy of their control. CRU scientists and graduate students collect valuable information on, for example, invasive plants, crayfish, mussels, snails, fishes, birds, and reptiles from throughout the United States. These range from studies to determine the movements and distribution of fishes, like invasive carps (for example, *Hypophthalmichthys molitrix*), brown trout (*Salmo trutta*), and northern pike (*Esox lucius*) to studies using environmental DNA (eDNA) to scan for presence of invasive zebra mussels (*Dreissena polymorpha*) and crayfish (Decapoda) in our Nation's lakes and rivers, to developing new methods for detecting spotted lanternflies (*Lycorma delicatula*) in orchards and suburbs of the northeastern United States.

Alaska Unit

Physiological performance of native and invasive northern pike: Implications for barrier design in invaded systems. Northern pike are an important native fish species north and west of the Alaska Mountain Range, but illegal introductions and their spread has led to thriving invasive populations in southcentral Alaska, where they are feasting on native and stocked salmon and trout. Although removing northern pike with nets can be effective, alternatives are needed to reduce the risk that northern pike will reinvade abundant, interconnected lakes and rivers. This project will quantify how waterfall height, plunge pool depth, water temperature, fish size, and body condition affect leaping abilities of northern pike. The results of this project will provide waterfall barrier parameters that aim to exhaust and prevent northern pike movement upstream, while reducing impacts on native species.

Silver Carp (*Hypophthalmichthys molitrix*)

Washington Unit

Improving modeling tools for combating invasive species. Invasive species represent significant threats to freshwater ecosystems in the Pacific Northwest. Management of invasive species requires effective allocation of limited resources for suppression or eradication, as well as robust information about invasive population structure, distribution, and rate of spread. There is a critical need for methods that combine data sources to inform management decisions. The Washington Unit is partnering with USFWS Columbia Pacific Northwest and Pacific Islands Regions, and the University of Washington to develop broadly applicable data integration and modeling approaches for two high priority invasive species in the Pacific Northwest: flowering rush (*Butomus umbellatus*) and rusty crayfish (*Faxonius rusticus*). This project will inform joint monitoring and management programs for these species, and similar invasive species, in the Pacific Northwest.

Minnesota Unit

Genetic biocontrol of invasive species: Understanding attitudes and risk perceptions. This study seeks to (1) understand Minnesota adult residents' attitudes, risk perceptions, and level of support for using genetic techniques in controlling two invasive aquatic species in Minnesota (zebra mussels and invasive carp); (2) understand differences in the level of support for using genetic techniques in these two cases; (3) understand the general preferences for using genetic techniques in the management of invasive species in Minnesota, the antecedents/consequences of these preferences, and the population heterogeneity related to these preferences; and (4) explore and gain an initial understanding of the potential concerns of Tribal communities in Minnesota for using genetic techniques for invasive species control.

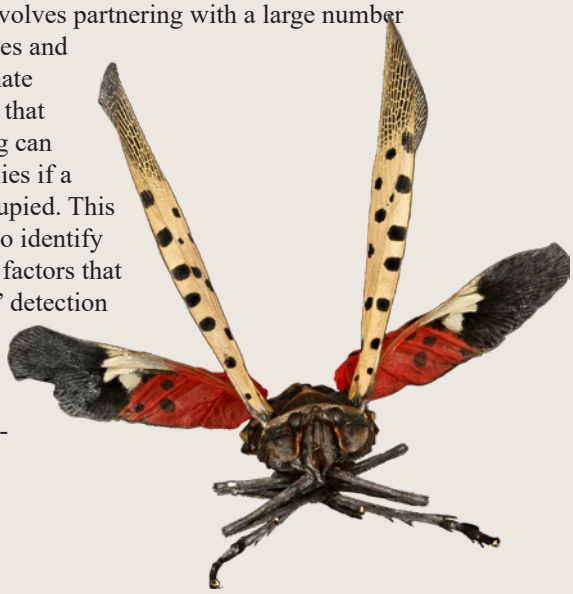
Zebra Mussels (*Dreissena polymorpha*)

Tennessee Unit

Relative population densities of invasive carp in the Tennessee River and Cumberland River drainages. Populations of invasive carp are expanding in multiple Tennessee River systems, but knowledge of current distributions and abundance is lacking. This invasion presents a threat to native aquatic species, fishing, and tourism. This project assesses spatial variation in relative abundance of the invaders in two Tennessee River reservoirs (Kentucky and Pickwick Lakes) and two Cumberland River reservoirs (Barkley and Cheatham Lakes), developing indices of carp abundance in dam tailwaters (located below the dams) above those four impoundments, evaluating tailwater sampling efficiency, and testing novel methods and models for sampling and control measures in Southeast United States reservoirs. Partners include the Kentucky Department of Fish and Wildlife Resources, Tennessee Wildlife Resources Agency, Mississippi Department of Wildlife, Fisheries, and Parks, and Alabama Department of Conservation and Natural Resources, as well as USFWS and USGS science centers.

New York Unit

Occupancy of spotted lanternfly using detection dogs (*Canis lupus familiaris*). When the spotted lanternfly arrived in Pennsylvania, severe ecological and economic damage ensued. Recently, the spotted lanternfly was detected for the first time in New York City. The goal of this project is to mitigate the negative impacts of the spotted lanternfly on the livelihoods of small agricultural producers and provide new tools to assist in the fight against invasive species. The insect's cryptic nature can make detection difficult, but early detection is key to protecting both producer livelihoods and ecosystems. This project involves partnering with a large number of State agencies and NGOs to estimate the probability that a human or dog can detect lanternflies if a location is occupied. This project will also identify environmental factors that influence dogs' detection abilities and model the probability of spotted lanternfly occurrence.



Spotted Lanternfly (*Lycorma delicatula*)

Species of Greatest Conservation Need and Threatened/Endangered Species

Every U.S. State and territory has identified Species of Greatest Conservation Need (SGCN) as part of a State Wildlife Action Plan (SWAP). These are species that should be conserved before they become too rare or costly to restore. Threatened and endangered species are species that have become so rare that State or Federal regulation and great expense may be necessary to recover their populations or habitats. CRU scientists, staff, and students are regularly asked by State and Federal partners to investigate the abundance, distribution, and habitat requirements of both groups of species; they also assist Federal agencies with assessments of the status of populations. This can entail collecting new data or analyzing existing data and determining the level of confidence (uncertainty) that decision-makers can place on the results.

The units in Alabama, Arizona, Florida, Mississippi, New Mexico, North Carolina, Missouri, Oregon, and Tennessee are engaged in developing data, tools, and analyses to support Species Status Assessment (SSA), the process by which USFWS informs decisions regarding the listing of species as threatened or endangered. At least 12 CRUs are conducting research to support SWAPs by providing information that could help States prevent the need for drastic actions for conservation of native species.

Maine Unit

Does predation limit Atlantic salmon recovery? In 2009, Atlantic salmon returning to the Penobscot, Kennebec, and Androscoggin Rivers were included in the Gulf of Maine population as a Federally endangered species. Where their ranges overlap, introduced smallmouth bass (*Micropterus dolomieu*) may compete with Atlantic salmon for physical habitat and food. Atlantic salmon populations may also suffer from direct predation and compete for resources with smallmouth bass in fresh water. As salmon smolts, or juveniles, migrate seaward, they encounter geomorphic barriers, changing flow, varying turbidity, and a gauntlet of predators, including brown trout, largemouth bass (*Micropterus salmoides*), smallmouth bass, and northern pike. The proposed work will characterize the role predation may have during early life history of salmon smolts.

Gray Wolf (*Canis lupus*)

Colorado Unit

Population models for endangered humpback chub (*Gila cypha*). Challenges to monitoring the population status and dynamics of endangered humpback chub include remote locations (the Colorado and Little Colorado Rivers), capture only being able to occur periodically, early life stages being difficult to tag, and fish being most accessible to capture only when spawning. Recently, arrays of PIT tag readers have been installed to increase the chance of tagged humpback chub being detected. A model that integrates PIT tag detections with traditional recapture data is being developed to better understand the population size and dynamics of humpback chub. This project is a collaboration of the unit, the USGS Grand Canyon Monitoring and Research Center, and USFWS. The results of the modeled population size and vital rates may better inform proposed management actions that affect the chub.

Humpback Chub (*Gila cypha*)

Mississippi Unit

Using a Bayesian belief network to structure Species Status Assessment of data-deficient species: A case study with piebald madtom (*Noturus gladiator*). The southeastern United States supports hundreds of freshwater mussel, fish, and crayfish species, but many are likely at risk of imperilment, with little information about their populations. This project focuses on a small, cryptic catfish species, piebald madtom, as an example study for implementing an SSA, using a Bayesian belief network and elicitation techniques from experts with the USFWS, Tennessee Wildlife Resources Agency, Mississippi Department of Wildlife, Fisheries, and Parks, U.S. Army Corps of Engineers (USACE), Mississippi State University, University of Tennessee at Martin, and Austin Peay State University. This project will be used to predict current and future conditions of piebald madtom populations and serve as an assessment framework for similar species.

Oklahoma Unit

Development, validation, and implementation of a survey protocol to evaluate distributions and habitat associations of Eastern whip-poor-will (*Antrostomus vociferus*) and other Oklahoma nightjars (*Caprimulgidae Linnaeus*). The Eastern whip-poor-will is a secretive bird species that is experiencing steep population declines across North America and is identified as a SGCN in Oklahoma and several other States. Yet, population status and habitat associations are unknown in Oklahoma, largely due to challenges in monitoring the species and other similar nocturnal birds. This project will increase information about the Eastern whip-poor-will and similar species in Oklahoma through the development, validation, and implementation of a survey protocol that can be used by Oklahoma Department of Wildlife Conservation to track nightjar distribution and trends. This research is a collaboration with the Oklahoma Department of Wildlife Conservation to provide a baseline for monitoring future changes in population status in Oklahoma and to inform conservation efforts across North America.

Oregon Unit

Spatial analysis of trends in tufted puffin (*Fratercula cirrhata*) breeding habitat on the Oregon coast. Tufted puffins are an iconic bird species in the Pacific Northwest that provide a wide range of services from ecotourism for local communities to transport of marine-derived nutrients to terrestrial habitats. Tufted puffin populations on the Oregon coast have declined by nearly 90 percent since 1989. In 2018, an SSA determined that factors related to breeding site conditions are one possible cause of tufted puffin decline; however, little is known about the specific characteristics of nesting habitat along the Oregon coast or how it relates to their population dynamics. This project will examine the distribution of suitable breeding habitat for tufted puffins on the Oregon Islands National Wildlife Refuge. Assessing how suitable tufted puffin breeding habitat characteristics have changed over time will provide necessary information to guide refuge managers in habitat restoration and support future adaptive management frameworks and decisions.

Tufted Puffin (*Fratercula cirrhata*)

Texas Unit

Species distribution modeling and Native Fish Conservation Area prioritization to guide landscape level conservation. In Texas, 48 percent of freshwater fish are considered as SGCN. Therefore, integrated watershed-scale conservation and management plans are needed to implement effective river conservation for multiple species simultaneously. This project will use updated data and methods to predict current species distributions and diversity, refine spatial prioritization of Native Fish Conservation Areas by identifying areas of greatest conservation value, and coordinate the use of supporting datasets and research products with conservation stakeholders. These results will be used to support and guide statewide conservation objectives and project planning within the Texas river conservation network. This is a collaboration among the Texas Parks and Wildlife Department, University of Texas, Austin, and USFWS.

Florida Unit

Alligator snapping turtle (*Macroclemys temminckii*) population viability and listing decisions. The Florida unit is assisting the USFWS Alligator Snapping Turtle SSA team in development of a population viability model that predicts future abundance and extinction probability. The results inform the forthcoming listing decision for two species, alligator snapping turtle and Suwannee alligator snapping turtle (*M. suwanniensis*). The Florida Unit partnered with USFWS to establish analysis units (which are geographically relevant spatial subdivisions for population traits) for two alligator snapping turtle species to create the representation and redundancy components of an SSA, and assess the current status of alligator snapping turtles across their native geographic range and within each analysis unit. The future status of the population was assessed, and the model simulated alternative scenarios that examined the effects of on-going threats and stressors to the species. Monitoring recommendations and protocols for alligator snapping turtles across their range were established to inform future decision-making by USFWS.

Alligator Snapping Turtle (*Macroclemys temminckii*)

Decision Science or Structured Decision Making

Decision science uses quantitative methods to aid managers, biologists, and administrators facing complex problems or great uncertainty. It may involve the integration of data or expert judgement, and it usually incorporates measures of uncertainty. When applied to recurring decisions, such as the harvest of changing populations of fish and wildlife or changing conditions, this approach is known as Adaptive Management. The CRU has extensive expertise in the use of decision science to help resolve complex problems in natural resource management. Students engaged in these projects learn a variety of methods for analyzing uncertainty and eliciting information from experts to provide results and tools for wildlife and fisheries managers on issues, including wildfire in Alaska, turkey harvest in Pennsylvania and New York, deer harvest in Georgia and North Carolina, flow management in Maine Rivers, and imperiled mussel recovery in the Appalachians.

Georgia Unit

Incorporating structured decision-making and alternative sources of data into management of white-tailed deer (*Odocoileus virginianus*) in Georgia. Management of deer populations across Georgia is challenging because of regional variation in a variety of factors, such as habitat quality. Self-reported harvest data available may not be reliable for harvest management decisions because they contain unknown biases. This project will investigate the utility of these data sources under a structured decision-making framework. This work is being performed in a collaboration between the University of Georgia and the Georgia DNR. Results will be used to identify candidate harvest frameworks that address the goals of stakeholders and priorities for the collection of data to inform management.

New York Unit

Eastern wild turkey (*Meleagris gallopavo silvestris*) harvest modeling. Several states have recently expanded spring hunting opportunities for Eastern wild turkeys from half-day to all-day hunting. Despite declines in turkey populations in New York, surveys of small game hunters and turkey permit holders indicate that a majority of hunters still have interest in all-day spring turkey hunting. This project is a collaboration with Cornell Center for Conservation Social Sciences to investigate the effects of all-day hunting during spring on turkey populations and hunter satisfaction on experimental Wildlife Management Units. The results will provide the New York State Department of Environmental Conservation with a comparison of all-day and half-day hunting on harvest and survival rates, along with hunter satisfaction.

New York Unit

Lake Ontario salmonid management risk assessment: Refinement of predator-prey models. Lake Ontario supports a thriving Chinook salmon (*Oncorhynchus tshawytscha*) fishery. Sustainable management of this resource requires maintaining a balance between predator numbers and alewife (*Alosa pseudoharengus*), the primary Chinook salmon prey. This project is developing state-of-the-art stock assessment tools to inform management decisions for Lake Ontario Chinook salmon. By combining stock assessments for predators (Chinook salmon) and prey (alewife), the New York Unit will develop a decision support tool that can lead to robust ecosystem level management decisions for fisheries in Lake Ontario and, more broadly, the Great Lakes.

Wildfire

Wildfire is a ubiquitous concern for many of CRU's cooperating State and Federal land managers, especially in the western United States, where fires have grown in frequency and intensity. CRU scientists are involved in all aspects of understanding species responses to fire and are working to assist forest and grassland managers with understanding the potential trade-offs with different management actions and scenarios. Currently, six units (Alaska, Montana, New Mexico, North Carolina, Pennsylvania, and Oregon CRUs) are actively engaged in 10 wildfire-related projects. A few notable examples are provided below.

Oregon Unit

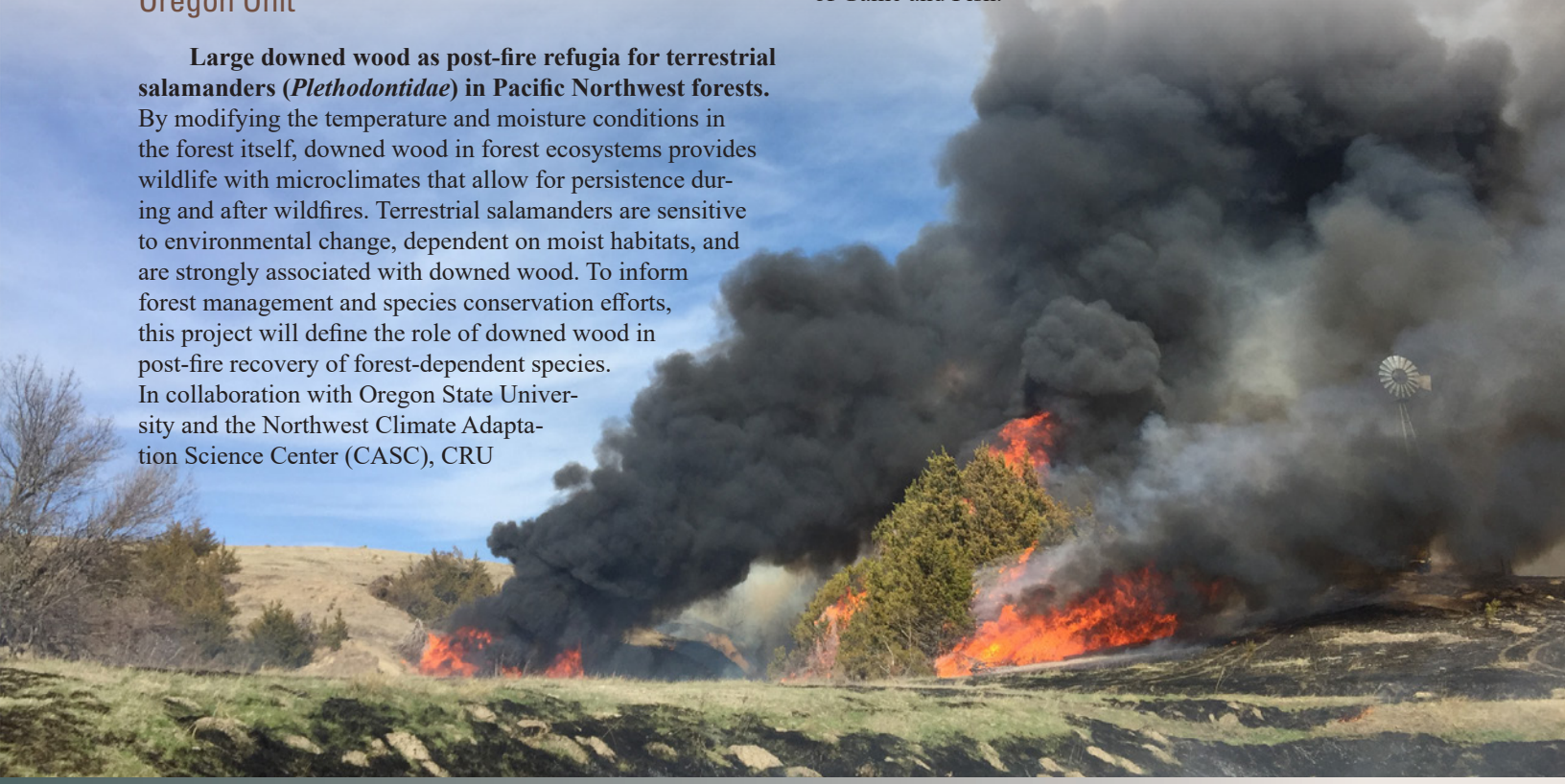
Demographics and habitat use of greater sage-grouse (*Centrocercus urophasianus*) in wildfire-affected habitats in Oregon. Southeast Oregon contains part of one of the largest contiguous sagebrush steppe habitats remaining within the extant range of greater sage-grouse. During the summer of 2012, several large wildfires included more than 1M acres of Oregon greater sage-grouse habitat within their perimeters. This project is a long-term study to evaluate short- and long-term effects of large-scale wildfire on female greater sage-grouse demographics and habitat use and selection. The research findings will inform prioritization of areas for post-fire habitat rehabilitation and restoration and help identify areas requiring further protection and (or) active management to reduce the risk of wildfire and ensure greater sage-grouse population persistence.

Oregon Unit

Large downed wood as post-fire refugia for terrestrial salamanders (*Plethodontidae*) in Pacific Northwest forests. By modifying the temperature and moisture conditions in the forest itself, downed wood in forest ecosystems provides wildlife with microclimates that allow for persistence during and after wildfires. Terrestrial salamanders are sensitive to environmental change, dependent on moist habitats, and are strongly associated with downed wood. To inform forest management and species conservation efforts, this project will define the role of downed wood in post-fire recovery of forest-dependent species. In collaboration with Oregon State University and the Northwest Climate Adaptation Science Center (CASC), CRU scientists are studying the relations between downed wood, microclimate, and wildfire on terrestrial salamander diversity. The work will provide managers with information on quantity and quality of downed wood needed to maintain protective microclimate conditions, and buffer forests from climate-driven wildfires.

New Mexico Unit

Responses of large mammals to forest restoration treatments in the southwest Jemez Mountains, New Mexico. Decades of fire suppression, overgrazing, and logging in the western United States have resulted in increased tree densities, altered wildlife habitat, and increased risk of stand-replacing wildfires. Land managers are currently implementing landscape-scale treatments in efforts to mitigate catastrophic wildfires and to restore historical forest conditions. The New Mexico Unit is monitoring the responses of mule deer, elk, black bear (*Ursus americanus*), and mountain lion (*Puma concolor*) to forest restoration treatments associated with the Southwest Jemez Mountains Collaborative Forest Landscape Restoration Project. Specific responses will include assessing changes in forage conditions, movements, and resource selection of mule deer, elk, black bear, and mountain lion in relation to prescribed fires, restoration thinning, and previous wildfires. The project will allow for informed design and implementation of restoration treatments that simultaneously mitigate wildfire risk and enhance habitat conditions for these species. This research is a collaboration among the New Mexico CRU, Texas Tech University, NPS, U.S. Forest Service (USFS), Jemez Pueblo, and New Mexico Department of Game and Fish.



Diseases of Fish and Wildlife

The coronavirus pandemic, Chronic Wasting Disease (CWD) in white-tailed deer, and white-nose syndrome in bats have spawned great interest in diseases of native fish and wildlife. Many aspects of widely known diseases of wild (as opposed to domestic) animal populations are poorly understood, including their ecology, incidence, distribution, and methods for reducing effects of disease on culturally and economically important species. CRU scientists are developing databases for sharing information about important wildlife diseases, such as coronaviruses in North American bats and CWD in ungulates. Research on the ecology and management of CWD is ongoing in at least eight States. Little is known regarding the ecology of lesser-known diseases in many other species. CRU scientists and students are contributing to data on the occurrence, causes, effects, and control of disease in trout and other salmonids, sea turtles, bighorn sheep (*Ovis canadensis*), bats, amphibians, and other animals which will be used for prevention and control measures.

Minnesota Unit

Tracking bats (Chiroptera) and coronaviruses through North American Bat Monitoring Network: Human dimensions of viral transfer. This work will leverage and bolster the existing North American Bat Monitoring Network so that scientists can better track and predict occurrence of coronaviruses in North American bats. This information will help to distinguish between perceived versus actual risk of viral transfer between human populations and wildlife, identify human behaviors that increase risk, and examine interventions that may mitigate risk. This study will help the Centers for Disease Control and Prevention, USFWS, and other agencies understand the risks of transmission between humans and bats, and to enhance wildlife management strategies that protect humans and wildlife from any risks that are found. The social science research proposed in this project will complement the coronavirus surveillance and modeling efforts described above. Human risk perceptions and behaviors will be documented to help clarify the relation between human choices and behaviors that influence the potential spillover transmission of coronavirus.

Montana Unit

Statistical model development to inform disease management in Montana. Understanding the epidemiological processes driving disease dynamics and their resulting impacts on population health is a fundamental need for management agencies tasked with maintaining the health of wildlife populations. However, because of the complexity of disease systems that invariably involve multiple factors, including the host, pathogen, and environment acting across space and time, developing tools to understand these systems and inform decisions is important. Such tools are critical for not only understanding past and current effects of disease on the health of populations, but also forecasting future impacts. Thus, they can inform decision-making aimed at protecting and restoring the health of wildlife communities. The goal of this project, in collaboration with Montana Department of Fish, Wildlife and Parks, is to develop and apply statistical approaches to meet this need.

Pennsylvania Unit

Establishing a national tissue and reagents repository for Chronic Wasting Disease. Research across multiple disciplines is needed to fully address the complexities of CWD and acquire the knowledge needed to limit or eliminate its spread. Research programs are emerging and maturing at multiple universities and government agencies; however, they are developing in parallel with little coordination. For example, in the Midwest alone, three large, independent studies have been initiated within the last 2 years to investigate the role of movement behavior in shaping epidemiological models of CWD. The intent of this project is to form a multistate consortium to improve information exchange among universities and researchers with common goals, but different backgrounds and knowledge bases. Increased collaboration would improve research quality and avoid duplication of work, at a critical time when effective solutions are needed quickly.

Brown Bat (*Myotis lucifugus*)

Utah Unit

Chronic Wasting Disease in Utah: Development of a risk-based CWD surveillance system with updates for the statewide CWD management plan. The overall goal of this research is to expand and combine existing CWD surveillance data needs with information on deer and elk movements, habitat use, and landscape factors. This will allow for better understanding the most likely paths of CWD spread, and provide the foundation for creating a revised, scientifically sound, risk-based CWD surveillance system. This project is part of a collaboration with the Utah Division of Wildlife Resources and Utah State University Department of Wildland Resources. Current and past CWD data will be used to create a comprehensive risk map for the State that will help managers and researchers to better understand what is currently known, identify high risk locations for CWD spread, help prioritize areas for sampling, and formulate appropriate management actions or alterations.

Wisconsin Unit

Deer movement and Chronic Wasting Disease spread in southwest Wisconsin. This project investigates how landscape heterogeneity, seasonality, and white-tailed deer movement behavior affect CWD spread. The project will investigate the impact of CWD infection on deer movement behavior, and the reverse, the impact of deer movement behaviors and contacts on CWD spread. This research will document the times and places where deer are most likely to congregate, along with biotic and abiotic factors that alter movement patterns and contact rates, which will help predict CWD dynamics and inform management activities. Understanding why CWD spreads more quickly in some areas than others is critical to forecasting CWD distribution and targeting management actions to slow transmission. This project is part of a collaboration with the University of Wisconsin at Madison, the USGS National Wildlife Health Center, and the Wisconsin DNR.

Iowa Unit

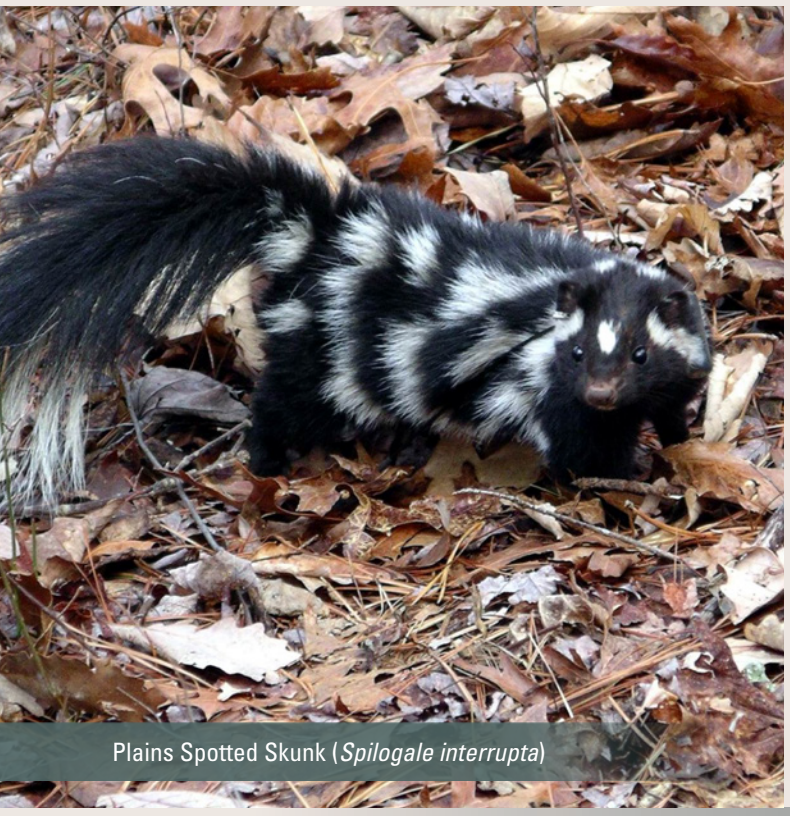
Bighorn Sheep Respiratory Disease monitoring. Glacier National Park provides refuge to several iconic North American species, including bighorn sheep (*Ovis canadensis*), whose range occurs on diverse DOI lands. Across this range, bighorns face the ongoing threat of a polymicrobial infection, Bighorn Sheep Respiratory Disease, which can reduce juvenile survival for many years, decimate populations, and lead to local extinctions. Although Glacier National Park's bighorns are thought to be free of the disease, a corridor of contiguous wilderness connects Glacier National Park to bighorn sheep populations that have tested positive for the most critical pathogen associated with this disease. As such, efficient biosurveillance programs are essential to anticipating and mitigating the effects of Bighorn Sheep Respiratory Disease outbreaks in Glacier National Park. However, molecular screening for Bighorn Sheep Respiratory Disease is financially and logistically challenging, requiring physical capture and multiple lab tests. Capture-based monitoring does not favor large-scale, continuous biosurveillance, thereby hindering risk assessment. The Iowa Unit is addressing this issue by developing an animal-behavior-based, citizen-driven biosurveillance program for Bighorn Sheep Respiratory Disease in Glacier National Park. The Iowa CRU is cooperating with NPS, USFS, and Montana Department of Fish, Wildlife and Parks staff on this project to provide the NPS with a tool to detect Bighorn Sheep Respiratory Disease for determining when mitigation strategies are necessary.

Mule Deer (*Odocoileus hemionus*)

Wyoming Unit

Research and monitoring of Wyoming toad (*Anaxyrus baxteri*) reintroductions: Linking survival, behavior, and genetics to inform species recovery. The Wyoming toad is one of the most endangered amphibians in North America, which rapidly declined in the 1970s due to unknown causes. A small population at Mortenson Lake National Wildlife Refuge, Wyoming, sustained by captive-release is now one of the only known, non-captive populations of Wyoming toads. USFWS recently improved captive facilities to allow regular release of adult Wyoming toads into the wild to foster increased reproduction and survival. This resulted in notable increases in reproduction, as evidenced by regular wild breeding, but changes in survival are questionable because the released animals are being observed less frequently than expected. The Wyoming Unit is collaborating with USFWS to track the fate of Wyoming toads at reintroduction sites across the Laramie Basin to assess the interaction among individual survival, behavior (such as, habitat and hibernacula selection), genetics, and disease, with the specific goal of identifying how these linkages can be used to facilitate recovery of the species. Data collected is providing valuable information for the reintroduction and recovery of the Wyoming toad. This information will be used to inform release strategies, monitoring, and potential captive breeding.

Wyoming Toad (*Anaxyrus baxteri*)



Plains Spotted Skunk (*Spilogale interrupta*)

South Dakota Unit

Distribution, habitat selection, and survival of plains spotted skunks (*Spilogale interrupta*) in South Dakota. The plains spotted skunk is a recently recognized species and has been petitioned for listing under the Endangered Species Act (ESA). Long-term harvest trends and anecdotal evidence indicates widespread population declines of spotted skunks across their range with notable declines in the Great Plains region. Although a mechanistic driver of these declines has not been identified, current hypotheses attribute habitat loss, intraguild competition, and disease as major factors. Key gaps in in knowledge for plains spotted skunks highlight the critical need for research into their population demographics. Project objectives are to delineate the population distribution, quantify how ecological and biological factors correlate with habitat selection, and estimate survival rates of plains spotted skunks in South Dakota. The study is a collaboration between the South Dakota CRU, South Dakota State University, and the South Dakota Department of Game, Fish and Parks.

Advanced Technologies

CRU scientists fully embrace new technology and the use of novel approaches to address the information needs of policy and decision makers. Currently, 28 units are actively engaged in 53 projects that include some aspect of advanced technology. Development of remote sensing techniques include the following: camera trap arrays, placed to detect animals in various habitats (for many species, from spotted skunks and bald eagles [*Haliaeetus leucocephalus*] to fishes and crabs); bioacoustic technology (for multiple bat species, and underwater calling frogs); remote operated vehicles (for a variety of lake and marine fishes); and unmanned aerial vehicles (for colonial nesting birds). Many of these remote sensing projects were coupled with developing artificial intelligence to identify images and sounds. Scientists also embraced technology through development of eDNA methods for assessments of biodiversity and presence of rare or endangered species, use of stable isotopes to identify critical stopover sites for waterfowl and lake food webs, and use of new geotracking tags to identify key habitat associations for Caribbean seabirds, secretive marsh birds, and burrowing owls (*Athene cunicularia*). The following unit projects provide a few examples of how scientists used advanced technology to develop cost effective sampling strategies to address species occurrence and abundance across a variety of landscapes.

Washington Unit

Advancing sustainable shellfish aquaculture through machine learning and automated data collection on fish communities. Washington is the Nation's leading producer of farmed shellfish, contributing approximately $184M to the State economy, supporting more than 1,900 jobs, and supplying fresh shellfish to consumers around the globe. Understanding how shellfish aquaculture functions as nearshore habitat relative to uncultivated areas will help resource managers assess potential tradeoffs when planning the sustainable expansion of shellfish aquaculture. In collaboration with researchers from NOAA Fisheries and shellfish growers in Puget Sound, the Washington Unit is using underwater cameras to document nearshore fish (including outmigrating salmonids) and crabs in both shellfish aquaculture and uncultivated nearshore habitats. Subsets of these video data were processed manually to address questions of aquaculture habitat use. Optimization of video processing will enable use of this technology to answer key questions about how fish are using nearshore habitats. Video processing will allow for expansion of this collaborative, industry-supported data stream to improve understanding of the ecological function of shellfish aquaculture, as well as inform public perception on the marine ecology surrounding these farms.

Dungeness Crab (*Metacarcinus magister*)

Wisconsin Unit

Development of point-of-use invasive species eDNA screening approaches. Many invasive species originate via trade and commerce, such as through the ballast water of shipping vessels or through the food trade. Eradicating invasive species is notoriously difficult; therefore, preventing their introduction is critical to controlling their spread. Enabling invasive species surveillance at discrete points of entry is a promising approach to detecting and preventing new invasions. This project is developing eDNA tools to enable point-of-entry screening of various substrates for numerous invasive species. The work is a collaboration between the Wisconsin CRU and the USGS Upper Midwest Science Center. These tools would allow port agents to detect invasive species before they enter the country, reducing the likelihood of establishing new invasive species.

Idaho Unit

Identifying migratory routes and wintering grounds of burrowing owls that rely on Department of Defense installations in the western United States. Burrowing owls were once a common bird in grasslands throughout North America but are now recognized as a Bird of Conservation Concern by USFWS at the national level. Despite population declines, burrowing owls are present on many Department of Defense (DOD) installations throughout the western United States. This project will identify wintering grounds and migratory routes of 200 burrowing owls nesting on DOD lands through the use of geolocators. The project represents a large collaborative partnership among 17 organizations, including the USGS, DOD, Canadian DOD, and Canadian Wildlife Service. Identifying migratory routes and wintering grounds for burrowing owls that breed on DOD installations will help determine shared management responsibility and allow for the development of the most cost-effective management plans for recovery. The results will identify priority management needs for this declining species and help reduce potential conflict with the military mission (primarily owl collision with aircraft) on DOD installations.

California Unit

Juvenile rearing distribution of threatened coho salmon (*Oncorhynchus kisutch*) at habitat restoration sites on the Hoopa Valley Reservation. Coho salmon appear to be at very low abundance in streams on the Hoopa Valley Reservation. Therefore, relying only on visual observation and capture of coho salmon is likely to underestimate the extent of their distribution. This project will combine standard visual surveys with eDNA sampling to determine the presence of coho salmon. This multimethod approach will also provide insight regarding the potential for eDNA surveys to evaluate small-scale patterns in coho salmon distribution associated with restoration activities. The Hoopa Tribe made investments in habitat restoration and improvement projects to aid in coho salmon recovery in streams on Tribal land. Results of this project will provide information necessary to assess coho salmon use of restored and unrestored sites to guide future restoration efforts. This project is a collaboration between the USGS, Hoopa Tribe, and Humboldt State University.

Arkansas Unit

Using hydrophones to survey for underwater calling frogs (Ranidae). An important step in conserving wildlife is understanding where species occur and how many individuals are present. Audio surveys are often used to collect such data for species that vocalize in a way that is readily audible to the human ear or to recording devices (for example, birds and frogs). However, emerging research indicates that some frogs primarily or exclusively call underwater and these vocalizations rarely break the air-water surface and are thus unlikely to be detected by surveyors. Therefore, to determine if an efficient and cost-effective methodology can be established to document the presence, distribution, and abundance of several imperiled frog species that primarily call underwater, a novel method using hydrophone recorders is being tested at sites in Georgia, Arizona, and Arkansas. This tool, if successful, could provide land managers with an innovative and important new methodology to survey for, and subsequently conserve, these imperiled species. Partners for this project include the Arkansas Unit, Cornell University, and USACE.

Burrowing Owl (*Athene cunicularia*)

New Mexico Unit

Using MYY-male brook trout (*Salvelinus fontinalis*) as an eradication tool of wild brook trout populations in New Mexico. In New Mexico, native Rio Grande cutthroat trout populations are experiencing a decline owing to loss of habitat and competition from nonnative brook trout. Viable removal options for nonnative trout have been limited to chemical piscicide and manual removal. Piscicides are effective, but are nontargeted and kill desired species, and manual removal has a low success rate. A novel, genetic-based approach, Trojan male (MYY, supermales) brook trout, may offer a species specific and cost-effective method of eradicating invasive brook trout. MYY brook trout produces only male offspring and will, theoretically, drive the wild brook trout population to 100 percent males and eventual eradication. This project will assess the efficacy of using MYY brook trout to shift sex ratios of selected populations of wild brook trout toward all male fish and eventual elimination. The results have widespread potential if the Trojan male approach is successful as a targeted and efficient management tool for eliminating undesired species to enhance future conservation efforts of native fishes. Collaborators for this project include the New Mexico Department of Game and Fish, Turner Enterprises, and USFS.

Arizona Unit

An integrated approach to using MYY technology and mechanical control methods for invasive fish control. Nonnative fishes have substantial impacts on native fishes through competition and predation. Targeted removal of the most harmful, nuisance species has been elusive. This research examines the feasibility of producing supermales (Trojan sex carriers; MYY) of common invasive species of the southwestern United States. The feasibility of integrated control of nonnative species will be modeled using mechanical removal to reduce the population first, and then stocking different numbers of supermales to the population. Results will allow for the manipulation of the sex of fishes to produce all-male offspring that will spawn with existing nuisance fishes and may, over time, reduce and even eliminate their populations. Partners for this project include the Arizona Unit and Bureau of Reclamation (BOR).

Brook Trout (*Salvelinus fontinalis*)

Grassland Management and Restoration

CRU scientists are conducting research on the management and restoration of a variety of grassland communities across the country. Coastal tidewater grasslands in Virginia, piedmont grasslands in Georgia, mesic grasslands in Montana, and open grasslands throughout the central United States support biologically diverse communities and play a critical role in maintaining the abundance of many obligate species and species of greatest conservation concern.

Arkansas Unit

A rapid mapping tool for quantifying grassland management outcomes in the southeastern United States. In grasslands—the North American biome with the greatest loss of biodiversity—documentation of successful restoration and management is imperative for building large-scale restoration programs. However, quantifying outcomes from grassland management efforts is made difficult by the lack of tools to rapidly map and track core grassland habitats and grassland biodiversity responses to management. In this project, the Arkansas unit will attempt to address this need by developing a rapid mapping tool to quantify grassland management outcomes on public and private lands. The tool is designed to identify and map grassland habitat cores to quantify grassland bird community responses to management in, and surrounding, three USFWS Arkansas refuges, focusing on southeastern grassland species of conservation concern. Tools and products from this project may facilitate grassland management strategies in the Arkansas refuges, provide grassland bird community and population trends, and help determine the applicability of this approach for public and private lands across the southeast region of the United States. Other collaborators for this project include the Arkansas Game and Fish Commission, USDA Natural Resources Conservation Service (NRCS), and Quail Forever.

Arkansas Unit

Conservation outcomes in Great Plains rangelands. For the past several decades, scientific research has quantified catastrophic outcomes to rangeland resources owing to woody plant encroachment. These outcomes include collapses in livestock production potential and rancher profitability, increased risks of wildfire danger and water security, displacement of wildlife habitat, and losses to important social and community programs (for example, revenue generated for public school education). However, scientific documentation of positive conservation management and strategy outcomes is limited, leading to slower widespread adoption of successful strategies. This project leverages major advancements in monitoring technology (such as, the Rangeland Analysis Platform), alongside various wildlife datasets to provide more rapid outcomes-generation for partners across the Great Plains. Quantifying spatially explicit changes in rangeland productivity, cover, and state transitions (that is, change in conditions) is central to this approach and improve understanding of the complex responses of more specialized outcomes-based assessments. This project is a collaboration between the Arkansas CRU, USDA NRCS, University of Montana, and University of Nebraska-Lincoln. USDA NRCS State conservationists across a four-State region of the Great Plains (Oklahoma, Kansas, Nebraska, and South Dakota) agreed to cooperatively increase conservation efforts, develop more effective strategies, and reduce the risks posed by woody plant encroachment to rangeland outcomes. Timely documentation of the benefits of new conservation practices will equip agencies and private land managers to solve the woody encroachment problem in the Great Plains.

Virginia Unit

Avian community response to grassland restoration at Rappahannock River Valley National Wildlife Refuge. Rappahannock River Valley National Wildlife Refuge (RRVNWR), located in the tidewater of Virginia, is a network of both remnant and restored grasslands. Over the past several years, surveys of grassland sites confirmed the presence of target grassland bird species, such as grasshopper sparrows (*Ammodramus savannarum*), field sparrows (*Spizella pusilla*), blue grosbeaks (*Passerina caerulea*), and northern bobwhite (*Colinus virginianus*). This project will determine whether Autonomous Recording Units (ARUs) can be used to monitor avian metapopulation dynamics in grassland ecosystems at the RRVNWR and collect baseline community and abundance data for long-term assessment of grassland restoration success. Objectives of this project are to: (1) determine which bird species can be reliably surveyed by ARUs and detected by automated call identification software; (2) estimate species occupancy and indices of abundance (estimated by call frequency and duration) across diverse grassland habitat patches; and (3) evaluate community similarity among habitat patches as a function of habitat characteristics.

Georgia Unit

Identifying pollinator habitat along powerline right-of-ways in the Georgia Piedmont. The Piedmont prairie is a biologically diverse grassland found in Georgia, hosting several plant species that allow pollinators, including the monarch butterfly (*Danaus plexippus*), to complete their life cycle. This diversity is under threat as a result of habitat fragmentation caused by incompatible land uses, but power line right-of-ways may provide an opportunity to conserve these grasslands and maintain some degree of habitat connectivity. Little is known about the occurrence and distribution of Piedmont prairies along power line right-of-ways. Identifying these sites will assist managers in decision-making about resource allocation between management of existing prairie habitat and creation of new habitat. The University of Georgia is conducting this work in collaboration with the Georgia Power Company and the Electric Power Research Institute. This project will contribute to basic understanding about the distribution and abundance of Piedmont prairies within the power line right-of-ways network in Georgia.

Kansas Unit

Patterns of greenness in the southern Great Plains and their influence on reproduction of declining lesser prairie-chicken (*Tympanuchus pallidicinctus*). Using the Normalized Difference Vegetation Index (NDVI) to identify temporal patterns in greenness values via satellite imagery that describe site-specific plant phenology (therefore, temporal variation in biotic characters) has been proposed for evaluating habitat quality in grasslands. Several grassland bird species, including lesser prairie-chickens, need both residual grassland cover and disturbed areas to reproduce. Combining phenology-based metrics with field-collected data could be useful for identifying high-quality reproductive habitat and monitoring grassland habitat. The project is a collaboration with USFWS and Kansas State University. Results may provide an assessment of the utility of NDVI and other phenology-based metrics for estimating lesser prairie-chicken reproductive habitat quality, remotely, over broad spatial scales, as well as monitor effects of climate change on available habitat.

Montana Unit

Qualifying the response of sagebrush-obligate birds to fence-modifications and encroaching conifer removal. Grazing infrastructure and conifer encroachment have negative effects on sagebrush-obligate birds. Recent sage-grouse (*Centrocercus urophasianus*), a sagebrush-obligate bird species, research in the Centennial Valley, Montana found lower nest survival rates for females nesting near fences than females nesting farther from fences. Consequently, fences in the Centennial Valley were modified to reduce perches for avian predators and allow facilitated movements of ground predators under fences. This research will monitor sage-grouse in areas of fence modifications to evaluate effects of these modifications on nest and brood survival, and to inform the management of grazing infrastructure to avoid negative impacts on breeding sage-grouse. Additionally, to better understand the negative effects of conifer encroachment, efforts have been funded to remove as much as 10,000 acres of conifers in mountain big sagebrush habitats across five sites, including State and Federally owned lands across the sage-grouse core geographic area of southwestern Montana. This research will quantify changes in sagebrush-obligate songbird populations, following conifer removal, and inform management of conifer trees in sagebrush habitats for improving sagebrush bird populations.

Sharptail-grouse (*Tympanuchus phasianellus*)

Water Allocation, Drought, and Ecological Flows

Water security and allocation for human use and ecosystems is a key challenge facing our nation. Water needs and allocation decisions for competing uses are made locally at watershed scales and are heavily reliant on regional drivers, such as climate, season, allocation policies, upstream uses, and downstream flow requirements. In addition, the effects of drought on water availability for many competing needs usually occur at critical times for some uses (for example, production for agriculture, juvenile rearing periods for instream fauna). Scientists at 15 CRUs are engaged in more than 40 projects related to how water availability influences fish and invertebrate assemblages, fish migration, and fish population vital rates.

Montana Unit

Drought, water availability, and the implications for fish populations. In semi-arid ecosystems, water availability is a critical resource for populations of many fish species, but spatial and temporal water availability data are lacking. Climate change and increased water abstraction will increase the frequency and intensity of drought, but the ecological implications are not well understood. Maps of spatial and temporal variation in water availability will better quantify needs and implications for fish populations and may be useful in the planning and prioritization of management actions. This project is a collaboration with the Wyoming Landscape Conservation Initiative.

Arkansas Unit

Effects of flow regime and habitat on fish assemblage structure. An important question in conservation ecology is: how do fishes of conservation concern use habitats and persist in their environment? The Arkansas Unit examined this question in streams with two distinct flow regimes, Groundwater Flashy and Runoff Flashy, in the Ozark Highlands of Arkansas, Missouri, and Oklahoma. Streams were sampled for fish and crayfish to assess the potential of refuge habitats in these streams, facilitate colonization and extinction dynamics during drought, and determine whether that differed between flow regimes. The project will assess the use of refuge habitats (or refugia) during drought to assess the potential of refugia as a driver of metapopulation dynamics. This research may inform resource manager's as to which habitats and flow regimes should receive conservation attention.

Oregon Unit

Development and evaluation of monitoring protocols to inform water resource decision-making. Natural resource managers invest considerable resources on surveillance monitoring programs to track the distribution and abundance of species. Although these data can be useful when evaluating spatial and temporal trends for species populations, using these data directly assumes the population dynamics signal is greater than the noise in the data that stems from the sampling process. This assumption is frequently not met. An equally important consideration is the integration of monitoring and natural resource decision-making. In this project, the Oregon Unit is evaluating the adequacy of long-term monitoring data from the San Francisco Bay Delta to depict the status of fish populations and developing alternative estimators that can be integrated with water resource decision-making. The Metropolitan Water District of Southern California is the collaborator for this project.

Hawai'i and Alaska Units

Influence of streamflow variability on fish populations as a proxy for understanding nutrient transport under climate change in Hawaiian and Alaskan streams. The effects of altered flow regimes on ridge-to-reef and icefield-to-ocean systems are poorly understood but have the potential to fundamentally alter the ecology and productivity of these systems. These systems harbor relatively high levels of biodiversity and endemic species, serve as important conduits of nutrient delivery to sensitive coastal environments, and are culturally and economically important to adjacent communities. This project will develop a multidisciplinary team to evaluate the effect of flow alteration on ridge-to-reef and icefield-to ocean watersheds. Specifically, this project will evaluate the effects of annual variability in flow conditions on growth and recruitment of invasive suckermouth catfish (*Hypostomus plecostomus*) in Hawaiian streams and compare findings to those of a complementary study linking hydrology to juvenile coho salmon growth in southeast Alaska. This joint effort leverages existing efforts to further investigate the effect of flow regime on fish growth and recruitment in ridge-to-reef and icefield-to-ocean systems. The project represents a collaborative effort between the CRUs, the University of Hawai'i, the University of Alaska Southeast, the University of Alaska Fairbanks, and USFS.

Population Monitoring and Advanced Modeling

Animal census is critical to conservation and management of populations because of changing distributions and habitats. CRU scientists have 77 projects conducting population monitoring and 69 projects involving advanced statistics and modeling. Many of these projects also include cutting-edge assessments of innovative census techniques, such as stable isotopes, eDNA, and satellite telemetry.

Massachusetts Unit

Evaluating the effects of management and stressors on at-risk species in Pine Barrens. Eastern box turtles (*Terrapene carolina*) are listed under the Massachusetts ESA as a species of special concern. This species occurs in Pine Barren habitats, where many other species are listed as species of special concern at the State and Federal levels. The Massachusetts Unit is assessing the population dynamics of the Eastern box turtle at Joint Base Cape Cod, a United States military installation on Cape Cod, Massachusetts. The project will explore the effects of parasitic fly larva on Eastern box turtle home range, survival, dispersal, and habitat selection. By collecting radio telemetry data and monitoring behavior and (or) distribution, comparison to records kept prior to prescribed fire implementation and parasitic larval infestation will be conducted. The results of this study will be used to inform the upcoming Federal listing decisions of species that inhabit Pine Barrens habitats by the USFWS. Collaborators include the USFWS, Massachusetts Division of Fish and Wildlife, and the Joint Base Cape Cod.

Eastern Box Turtle (*Terrapene carolina*)

North Carolina Unit

Determining Henslow's sparrow (*Centronyx henslowii*) population redundancy in North Carolina. Henslow's sparrow is a grassland specialist, migratory songbird with a rapidly declining habitat range owing to habitat loss and climate change. The species is a conservation priority for States and USFWS. In North Carolina, the species' stronghold is at the Voice of America Game Lands (VOAGL). Ongoing efforts are designed to estimate its population size and assess its response to fire management (resiliency) and determine its genetic distinctiveness (representativeness) from other populations. However, little is known about the sparrow's presence and abundance in North Carolina outside of the VOAGL. The project will identify the presence/absence of Henslow's sparrows at sites with suitable habitat parameters and develop a habitat range model for Henslow's sparrows in North Carolina. This work is important because the existence of other sparrow populations would spread the risk of local extinction and strengthen the basis for strategic habitat conservation plans to protect or co-manage occupied habitat. The project collaborators are the USFWS and North Carolina Wildlife Resources Commission.

Moose (*Alces alces*)

South Carolina Unit

Tracking Atlantic and Caribbean seabirds. The Caribbean and Bahamas support approximately 25 species of breeding seabirds. Despite the regions' importance to seabird conservation and diversity, seabirds there have been understudied, particularly with respect to migratory connectivity throughout the Atlantic. This project's goal has been to steadily increase baseline data on the spatial ecology of seabirds in the region by partnering with local NGOs to build local capacity. To date, scientists have collected tracking data from several species of pelagic (therefore, open ocean) seabirds in Mexico, Jamaica, Dominican Republic, Bahamas, British Virgin Islands, Saint Eustatius, and Tobago, in collaboration with Federal agencies, local universities, and NGOs. Additionally, one particular focus of research in the region has been to expand baseline data on the endangered black-capped petrel (*Pterodroma hasitata*), a species endemic to the area, nesting at only a few sites on Hispaniola. Considered globally endangered, the black-capped petrel is under review for listing by the USFWS. The CRU is conducting research on movement ecology, diet, and reproductive ecology with local partners and, to date, have conducted the only tracking efforts for this species.

Black-capped Petrel (*Pterodroma hasitata*)

Vermont Unit

Population ecology of moose (*Alces alces*) in Vermont. Concern has risen in Vermont and neighboring States over the past decade regarding high mortality and low recruitment rates of resident moose populations, which have declined. High winter tick infestations are considered a major cause of these trends. The Vermont Fish and Wildlife Department uses population models to estimate regional moose numbers and determine appropriate management actions. Model inputs, such as age structure, sex ratio, and mortality and recruitment rates are used to model moose population structure and viability. Management of Vermont's moose would benefit greatly from more precise estimates of these rates and a population viability assessment. This project is investigating rates of moose mortality, productivity, recruitment, and genetics of moose populations over a 3-year period in two Wildlife Management Units. These areas collectively constitute an important moose management region and contain 632 square miles of moose habitat with high moose densities (as many as 1.75 moose per square mile), high winter tick loads, and low deer densities. The study will contribute to a broader understanding of moose population trends in the Northeast region. This project is a collaboration between the Vermont Unit, University of Vermont, and Vermont Fish and Wildlife Department. It builds on work done in the neighboring States of New Hampshire, Maine, and New York.

West Virginia Unit

Development of a long-term paddlefish (*Polyodon spathula*) monitoring program on the Ohio River in West Virginia. Paddlefish is a unique, long-lived, and large-bodied fish species of the Mississippi River drainage. This species has undergone dramatic population declines owing to anthropogenic alterations of large river ecosystems. Many state natural resource agencies, including West Virginia, are conducting stocking programs toward recovery of paddlefish populations. A long-term monitoring effort is needed to evaluate the success of this program; this study will evaluate population status, movement patterns, and reproductive success of paddlefish in the Ohio River of West Virginia. Information from this study will inform management decisions for this species, aiding the West Virginia Division of Natural Resources toward their goal of a re-established population of paddlefish in the Ohio River. This research is a collaborative effort involving the West Virginia Unit, West Virginia University, West Virginia Division of Natural Resources, and Missouri State University.

American Paddlefish (*Polyodon spathula*)

Hunting and Fishing

When many people think of the CRU program, research related to hunting and fishing immediately comes to mind. CRU scientists are investigating multiple avenues of research in support of cooperators and the millions of individuals who hunt and fish. Twenty-seven CRUs are conducting nearly 80 projects on hunting and fishing. Topics include harvest models, evaluation of length and creel limits, urban hunting and fishing, angler behavior, adaptive management of deer, and improvements in census of animals. These fundamental, core projects deliver modern science solutions to complex problems.

Alabama Unit

Exploitation and catch of shoal bass (*Micropterus cataractae*) in the lower Flint River Basin and angler use, effort, and economic impact of the fishery. The Flint River, below Lake Blackshear in Georgia, supports a popular shoal bass fishery that is currently managed by a 305-millimeter minimum-length limit and a stocking program. Hydropeaking flows (therefore, highly variable flows) from Crisp County Dam have reduced shoal bass recruitment below the dam, prompting the Georgia DNR to initiate a stocking program in the 1970s that continues today. Below, the next dam—Albany Dam—is the second-longest undammed section of stream across the shoal bass range (150 kilometers). Reduced recruitment of shoal bass below Albany Dam occurs; an USACE 1-meter low water navigation channel from the cities of Albany to Bainbridge is maintained in the river reach. Effects of the navigation channel on the shoal bass population are unknown, but likely have resulted in deeper channels and swifter currents, which may exacerbate effects of hydropeaking flows. This project aims to estimate population metrics/rates (exploitation, hatch date, early growth, movement and habitat use) of shoal bass, and evaluate the current 305-millimeter minimum length limit, and harvest restriction scenarios on the population in the reach below Albany Dam. This work is being done in collaboration with Georgia DNR and will inform the agency regarding size and harvest limits for shoal bass.

Nebraska Unit

Comprehensive evaluation of the Nebraska outdoor enthusiast. The USFWS supports the National Survey of Fishing, Hunting, and Wildlife-Associated Recreation Survey in a nationwide effort to understand the hunting and fishing public and States often conduct their own surveys to inform local actions. The Nebraska Unit is analyzing a comprehensive database on license holders in Nebraska with the goal of helping inform and direct wildlife and fisheries management, as well as recruitment and retention efforts within the State. To date, scientists have used license purchase data to infer sportspersons change activity groups (hunting only, fishing only, a combination of hunting and fishing, and inactive). Change in activity groups occurs infrequently and varies little based on initial group participation. In addition, scientists developed a customizable, open-source, web-based application—huntfishapp—that allows users to easily interact with a license database. The huntfishapp serves as an informational resource, provides a framework for sharing information on license sales across an agency, and allows agencies and NGOs to become more knowledgeable of their customer base.

Louisiana Unit

Linking annual waterfowl productivity and Louisiana hunter-harvest to natal/molt origins using stable isotope ecology. Although continental populations of waterfowl are still above the long-term average, midwinter waterfowl counts in coastal Louisiana have been declining. For harvested waterfowl, understanding the strength of migratory connectivity and identifying links between source origins (for example, natal or molt origins) are important when developing sustainable management strategies. Throughout the management area, State agencies independently make decisions where to invest agency funding to support conservation and restoration efforts throughout the breeding grounds, and decisions are largely informed through capture-mark-recovery techniques. This project is a collaboration of researchers from the Louisiana CRU, University of Western Ontario, Louisiana Department of Wildlife and Fisheries, and Arkansas Game and Fish Commission. This project compares estimates of harvest derivation (proportions of total harvest from different populations of interest) using available banding data and stable isotope analyses of flight feathers in harvested waterfowl (such as, blue-winged teal [*Spatula discors*] and mallard [*Anas platyrhynchos*]). Data acquired will inform biologists on the efficacy of capture-mark-recovery methods to assess source-origins and migratory connectivity of managed waterfowl. Further, this study may demonstrate the utility of incorporating source-origins estimates via stable isotope analyses into long-term monitoring programs of harvested waterfowl, which can be used to track hunter harvest and population productivity.

Missouri and Pennsylvania Units

Quantifying the effects of climate change on fish growth and production to enable sustainable management of diverse inland fisheries. Fisheries managers need a greater understanding of the effects of temperature on fisheries productivity and growth and how these effects vary among populations to make informed harvest decisions. The Missouri and Pennsylvania Units are quantifying climate effects on inland fisheries by building upon and unifying work to support climate-smart fisheries management in inland lakes and the Great Lakes. The project will quantify changes in fish thermal habitat conditions, growth, and production for multiple managed species, encompassing a range of thermal preferences over a broad landscape. Together, this knowledge can enable fisheries managers to set realistic objectives to manage multiple economically important fish species under climate change.

Training the Next Generation of the Natural Resource Workforce

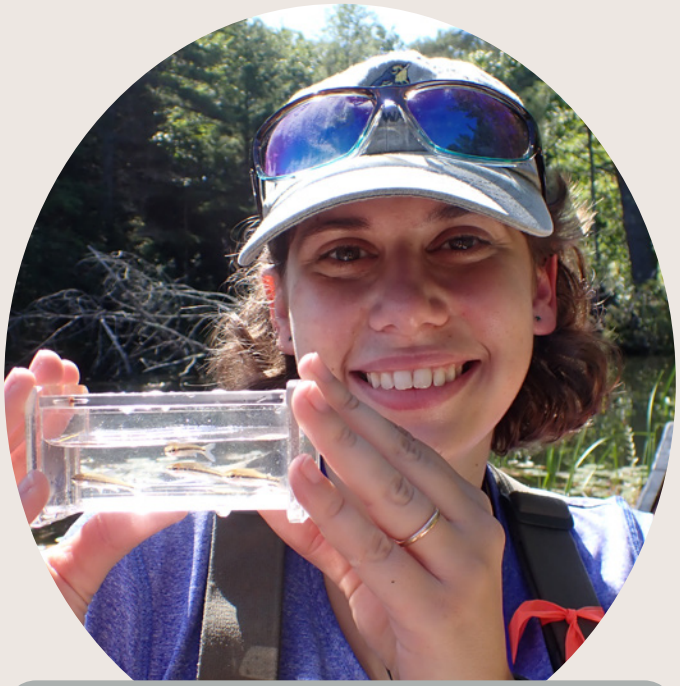
Graduate students are the backbone of the CRU program and go on to be leaders in the natural resource profession. Students are advised by unit scientists and conduct applied research projects that directly address current natural resource concerns of the State and Federal cooperators. Students also receive cutting-edge academic training from university cooperators and develop expertise on the issues of State and Federal natural resource management and protection agencies. Students graduating with the research experience are prepared to be effective members of the natural resource workforce. The following profiles are examples of graduate student research experiences with CRUs.

White Sturgeon (*Acipenser transmontanus*)

Graduate Student Spotlights

Lara Katz - University of Maine, Maine Unit

Research Project: Assessing the distribution and habitat of bridle shiners (*Notropis bifrenatus*) in Maine. Lara Katz is a Master of Science (M.S.) student with the Maine Unit and the Department of Wildlife, Fisheries, and Conservation Biology at the University of Maine. Lara was first exposed to fisheries science as an undergraduate, when she spent three summers studying stream recolonization by sea lamprey (*Petromyzon marinus*) and freshwater fish after dam removal. After her bachelor's degree, Lara spent 4 years working for Acadia National Park as a wildlife technician and environmental compliance assistant. Lara became interested in monitoring rare species as she researched Acadia's bat community using acoustics and radiotelemetry. Her interests in rare species monitoring and geographic information systems led her to return to the University of Maine to pursue her Master's degree. Her thesis research focuses on locating remnant populations of the bridle shiner, a rare native minnow, in southern and western Maine. She is using a combination of seine netting and eDNA sampling to locate the fish. Lara is also developing a predictive habitat model to help inform future surveys, long-term monitoring, and conservation actions. Her research is supported by, and in collaboration with, the USGS, Maine Department of Inland Fisheries and Wildlife, and the Maine Outdoor Heritage Fund.



Lara Katz holds up bridle shiners (*Notropis bifrenatus*) caught during a river seine net survey

Brandon Barlow - University of Nebraska-Lincoln, Nebraska Unit

Research Project: Angler behavior in response to management actions on Nebraska reservoirs. Brandon Barlow is a M.S. student participating in a 15-year research project, administered by the Nebraska Unit, designed to understand behavior patterns of anglers and how their participation is related to fish populations, fish communities and agency management actions. Within this long-term project, Brandon is testing whether the behavior of anglers that reside in an urban environment differs among neighborhoods, and the socioeconomic factors that compose the urban environment. Preliminarily data on angler behaviors differ among neighborhoods, primarily as a function of fish species targeted and the decisions to harvest captured fish. Brandon's findings will help managers refine management objectives for urban fisheries. Brandon will apply the skills and knowledge from his graduate program as he works toward creating smart water and environmental policy for the benefit of the public. In January 2023, Brandon will begin the prestigious National Sea Grant John A. Knauss Policy Fellowship, a national program that places exceptional early career graduate students with host offices of the Federal government for a 1-year fellowship in Washington, D.C.

Benjamin Miller - Utah State University, Utah Unit

Research Project: Experimental nonnative wood addition to enhance in-stream habitat for native desert fishes. Ben Miller is a M.S. student with the Utah Unit at Utah State University, where he is co-advised by Dr. Casey Pennock, Research Faculty in Watershed Sciences and Unit Leader, Dr. Phaedra Budy. Ben developed a strong passion for the conservation of imperiled desert fishes while working as a fish biologist at the Native Fish Lab of Marsh and Associates in Tempe, Arizona. Now, Ben is applying that passion to his graduate research where he is testing the efficacy of adding large woody debris in the form of cut Russian olive (*Elaeagnus angustifolia*), a nonnative tree, as a means of increasing physical and hydraulic complexity to enhance in-stream habitat for native desert fishes in the San Juan River. The San Juan River, like many other rivers in the Colorado River Basin, is affected by flow regulation, overallocation of water, and establishment of nonnative riparian vegetation, all contributing to broad scale habitat loss and simplification. Ultimately, this project aims to inform managers of the potential for native fish habitat enhancement by exploiting existing and abundant nonnative woody vegetation. Ben and his advisors collaborate with biologists from the BOR, USFWS, Navajo Nation, and other stakeholders of the San Juan River Basin Recovery Implementation Program.

Brandon Barlow conducting a creel survey to gather socioecological data in Nebraska.

Benjamin Miller holding an endangered razorback sucker (*Xyrauchen texanus*) captured at an experimental wood addition site on the San Juan River.

Technical Assistance

Technical assistance to our State and Federal cooperators is an integral part of the mission of the CRU program. The scientific and technical expertise of CRU scientists in areas such as natural resource management, experimental design, data analysis, modeling, and spatial statistics provided 150 reported technical assistance efforts in 2022 that ranged from 1 to 180 days in duration. Though extremely varied in scope across the program, a few common forms of technical assistance included involvement in SSAs (Alexander Archipelago wolves [*Canis lupus ligoni*], grey wolves, western gray squirrel [*Sciurus griseus*], bluestripe darter [*Percina cymatotaenia*], plains spotted skunk, and snail kite [*Rostrhamus sociabilis*]), facilitating structured decision making events for decision makers (candy darters [*Etheostoma osburni*], rosy finch [*Leucosticte arctoa*], mountain lions, and fish passage projects), participating in recovery teams for select species (for example, Mexican wolf [*Canis lupus baileyi*], flatwoods salamander [*Ambystoma cingulatum*], sharpnose shringer [*Notropis oxyrhynchus*], smalleye shiners [*N. buccula*], and Niangua darter [*Etheostoma nianguae*]), and conducting data analysis for a number of State and Federal agency cooperators.

Mexican Wolf (*Canis lupus baileyi*)

Diversity, Equity, Inclusion, and Accessibility

The CRU program is actively involved in multiple activities related to Diversity, Equity, Inclusion, and Accessibility (DEIA). Efforts to improve dialogue and hiring practices are underway, as well as a strong commitment to recruit and train graduate students from diverse backgrounds.

Cooperative Research Units Diversity, Equity, and Inclusion Committee FY22 Report

In 2020, the CRU Management Team received a letter signed by 15 female USGS scientists with three suggestions aimed at increasing diversity in the workforce: (1) require or encourage implicit bias training for Federal staff at units; (2) raise the profile of the issue with Unit Coordinating Committees at the outset of hiring; and (3) develop a dialogue amongst CRU staff to cultivate a culture that encourages collaboration, flexibility, and fairness. In response to the letter, the Acting Chief of CRU established a Diversity Equity and Inclusion Committee (DEIC) to identify actions and make recommendations to the Management Team that would promote diversity in hiring and workplace inclusivity. This action also supported multiple Executive Orders (14035, 13583,13985, 13988, 14020).

In FY22, the DEIC (Abby Powell, Amanda Rosenberger, Angela Fuller, Grace DiRenzo, Jeff Muehlbauer, Mark Henderson, Mark Scheuerell, Reynaldo Patino, Wendy Turner, and Barry Grand) accomplished several important goals. In 2021, they initiated the development of a mentoring program within CRU. First, they designed and implemented a survey sent to all unit scientists to determine the level of interest in a mentoring program, the desired format of mentoring relationships, and potential topics for discussion. Using the results of the survey as a guide, the DEIC then developed and facilitated a virtual workshop on attracting and retaining students from diverse backgrounds in April 2022. The workshop consisted of three breakout sessions: (1) recruiting and attracting students from diverse backgrounds; (2) retaining and mentoring students; and (3) suggestions for CRU leadership to help support these efforts by CRU scientists. The workshop was attended by 41 CRU scientists from 26 States. One outcome of the workshop was DEIC's development of a document, now in internal review, on best practices for recruiting and retaining students from diverse backgrounds.

DEIC has also developed a proposal for a plenary entitled: "Real talk: The Relentless Day-to-Day of Undoing Our Biases" for the upcoming CRU all-hands meeting in 2023. The DEIC is working with Dr. Mamie Parker and Dr. Maria Estrada as the invited speakers and facilitators of this plenary. The committee will also facilitate two breakout sessions: one that follows the plenary on unconscious bias and another that continues the discussion of the recommended practices for recruiting and retaining students from diverse backgrounds.

DEIA Awards

Four DEIA awards were presented to CRU scientists, staff, and students this year. The recognition is indicative of the commitment to DEIA in CRU.

Awards to Cooperative Research Unit scientists, staff, and students for their contributions to Diversity, Equity, and Inclusion.

[DOI, U.S. Department of the Interior; USGS, U.S. Geological Survey]

Recipient	Award	Organization
Dawn Childs (staff)	Secretary's Diversity Award	DOI and USGS
Sarah Converse (scientist)	Outstanding Diversity Commitment Award	University of Washington College of the Environment
James Lee (student)	Black and Latinx Birders Scholarship	Amplify the Future
Michael McInturff (scientist)	Outstanding Commitment to Diversity, Equity, and Inclusion	School of Environmental and Forest Sciences, University of Washington

American White Pelicans (*Pelecanus erythrorhynchos*)

Doris Duke Conservation Scholars Program Collaborative

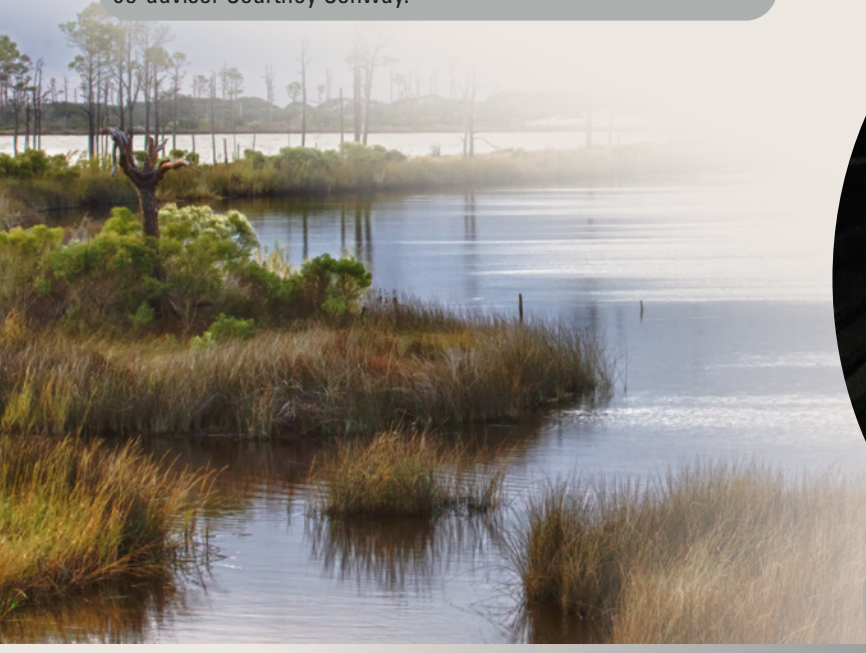
The Doris Duke Conservation Scholars Program (DDCSP) Collaborative is a 2-year undergraduate conservation, diversity, equity, and inclusion field program designed to provide students from underrepresented groups with an experiential introduction to a career in natural resources. The Arizona, Florida, Idaho, Massachusetts, and North Carolina Units are members of the collaborative. The students attend leadership training, work with scientists and graduate students on research projects, and are mentored by current CRU program graduate students and Federal scientists. The Doris Duke Conservation Scholars participate in paid summer internships with local, State, Federal, and Tribal agencies, as well as nongovernmental organizations.

University of Idaho Doris Duke Scholars at the USFWS National Conservation Training Center. From left to right, standing: Orion Cardenas-Ritzert, Abigain Cano Perez, Dr. Kerri Vierling (faculty co-advisor), Zander Zuniga; in front, Emily Cook. Photograph by co-advisor Courtney Conway.

Doris Duke Conservation Scholars Spotlights

Maya Encinosa - University of Florida, Florida Unit, 2nd Year Scholar

Maya Encinosa is a senior majoring in Wildlife Ecology and Conservation (pre-veterinary) and minoring in Pathogenesis at the University of Florida. She entered the DDCSP with an interest in wildlife diseases and policy, along with issues related to diversity, equity, and inclusion. During her first summer with the DDCSP, she worked alongside a graduate student mentor in Picayune Strand State Forest in Naples, Florida. Maya researched the effects of roadway proximity and type on habitat use by the Florida bonneted bat (*Eumops floridanus*) and presented her research, as a poster, at The Wildlife Society Annual Conference. This past summer, Maya followed her interest in veterinary pathology and coastal ecosystems to The Marine Mammal Center in Sausalito, California. She interned with the pathology group, assisting with and performing necropsies on marine mammals. Her research project on the characterization of urinary tract infections in California sea lions (*Zalophus californianus*) will be presented at the 2023 Wildlife Disease Association conference. The research and networking opportunities with the DDCSP led Maya to be accepted to participate in a Strategies for Ecology Education, Diversity and Sustainability program with the Ecological Society of America. Equally devoted to her local community, Maya looks forward to leading the Florida Student Chapter of the Wildlife Disease Association as President in her final semester.



Maya Encinosa holding a Florida Bonneted Bat (*Eumops floridanus*).

Christina Contreras - University of Idaho, Idaho Unit

Christina is a senior majoring in Wildlife Sciences with a minor in Rangeland Ecology and Management at the University of Idaho. She grew up in the small mountain town of Hailey, Idaho where she helped her dad with his landscaping business. As a first-generation Hispanic student, Christina has worked hard to maintain connections to her Hispanic roots and culture. Christina spent 2 years at a local community college and then transferred to University of Idaho to pursue a Bachelor of Science degree. Through the DDCSP, Christina gained a suite of professional skills. During her first summer with the DDCSP, she worked with a graduate student mentor studying the Northern Idaho ground squirrel (*Urocitellus brunneus brunneus*), a Federally threatened species endemic to only two counties in Idaho. Christina conducted her own research project that summer, examining the effects of soil properties on selection of winter hibernacula by these rare ground squirrels. She recently presented a poster on her research at the annual conference of The Wildlife Society. This past summer, she completed an internship at the Rachel Carson National Wildlife Refuge in Maine, where she worked with a variety of Federally threatened and endangered species. On her DDCSP application, Christina stated that there is nothing more important than having good communication skills, and that she wanted to join the DDCSP because she wanted to learn how to be a better leader in the wildlife profession. She hopes that the skills she has gained will allow her to make a difference in her community and in the conservation field.

Malvika Someshwar - University of Massachusetts, Massachusetts Unit, 2nd Year Scholar

Malvika's internship work was centered around animal behavior research, where she was primarily working with greater one-horned rhinoceros (*Rhinoceros unicornis*). Two rhinos at the Woodland Park Zoo in Seattle, Washington had developed Chronic Foot Disease (CFD), and it was her responsibility to help develop a numerical scoring system for a qualitative measure of discomfort. This project involved meetings with the zoo's veterinarian, rhino keepers, and welfare scientist, Dr. Bonnie Baird, as well as studying the animal's walking patterns and photographic documentation of the animal's feet through the year. Additionally, Malvika reviewed the space use and substrate preferences of the animals to determine how they liked to spend their time. This was important because substrate changes were implemented in an attempt to help with the rhinos' CFD. By conducting this research, the staff could observe the effect of the substrates. Malvika also studied the social dynamic between the two rhinos. Both rhinos are male and approaching 6 years old, which means that they will be separated, eventually. Studying their behaviors will help to determine when the separation will need to occur. In addition to her rhino research, Malvika helped to monitor the animals during concerts. The Woodland Park Zoo has a tradition of hosting concerts to help raise funds and awareness for conservation efforts. During these events, many of the animals were watched by the zoo staff to ensure their wellbeing. This research involved scoring animals on their behavior patterns and recording decibel readings for animals such as snow leopards (*Uncia uncia*), wallabies, wallaroos, and tree kangaroos. A third subset of work during the internship included submitting data for a new multi-institutional giraffe study headed by the Lincoln Park Zoo in Chicago, Illinois.

Christina Contreras with a Northern Idaho ground squirrel (*Urocitellus brunneus brunneus).*

Malvika Someshwar collects data on animal behavior at the Woodland Park Zoo, Seattle, Washington.

Notes from the Field

Prairie Fishes Initiative

Prairie streams are a valued ecosystem that dominates the mid-continental United States from the Canadian border to the southernmost States. The Prairie Streams and Fishes Collaborative (PSFC) is a geographically diverse group of fisheries professionals who share an interest in prairie streams and associated prairie stream fishes. Fisheries researchers and managers responsible for prairie stream fish conservation recognized the need for multi-State, multi-agency networking. Established in 2020, PSFC is a unique initiative that seeks to advance networking, research, management solutions, and synthesis for prairie streams ecosystems, using a combined virtual and in-person forum. Even though individual researchers and managers are working within individual prairie States and making important contributions, the formation of a formal group for collaboration benefits all. Participants in the PSFC include researchers and managers from nine States (Montana, Wyoming, South Dakota, Colorado, Nebraska, Kansas, Oklahoma, Texas, and Arkansas) that are employed by State agencies, Federal agencies (USGS science centers and USFWS), universities, NGOs, and nine CRUs (Alabama, Arkansas, Colorado, Iowa, Kansas, Oklahoma, Nebraska, South Dakota, and Wyoming).

The PSFC seeks to create opportunities for prairie fish professionals to make new contacts, advance the exchange of information at symposia, and catalyze thoughtful discussions about future activities. In 2021, the PSFC sponsored a full day symposium at the American Fisheries Society Annual Meeting in which individual researchers and managers summarized their recent work. In 2022, the PSFC organized a successful 2-day online workshop (fig. 3) that facilitated discussions of relevant human dimension issues, policy and practice concerns, research priorities, research syntheses, and ways to establish an integrated database. Synthesis projects, perspective publications, grants, and additional collaborations are emerging from this recent workshop. A graphical abstract of the collaborations is displayed on figure 4.

CRU scientists have played an important role in organizing and attending this collaboration (S. Brewer, Alabama; L. Bruckerhoff and J. Long, Oklahoma; D.Magoulick, Arkansas; M. Mather, Kansas; M. Moore, Iowa; J. Rogosch, Texas; J. Spurgeon, Nebraska; A. Walters, Wyoming; and D. Winkelman, Colorado). Strong CRU involvement with the PSFC merges applied research and ways to use data to advance solutions to management problems, which are two important motivations for CRU scientists. USGS scientists (D. Hu, N. Cole, P. Kocovsky, A. Hess, and M. Wildhaber) were pivotal to organization and participation of the PSFC. USFWS was strongly represented, as were multiple unit cooperators from each State. This PSFC initiative provides an opportunity for unit scientists and their collaborators to think more broadly and offers a different suite of solutions to management problems shared by State and Federal managers. The organizers of the PSFC look forward to creating and sharing this new model for collaboration and synthesis that advances ecological understanding, and the ability to manage valued, geographically expansive prairie fish resources.

Figure 3. Screenshot of participants in the Prairie Streams and Fishes Collaborative workshop in 2022.

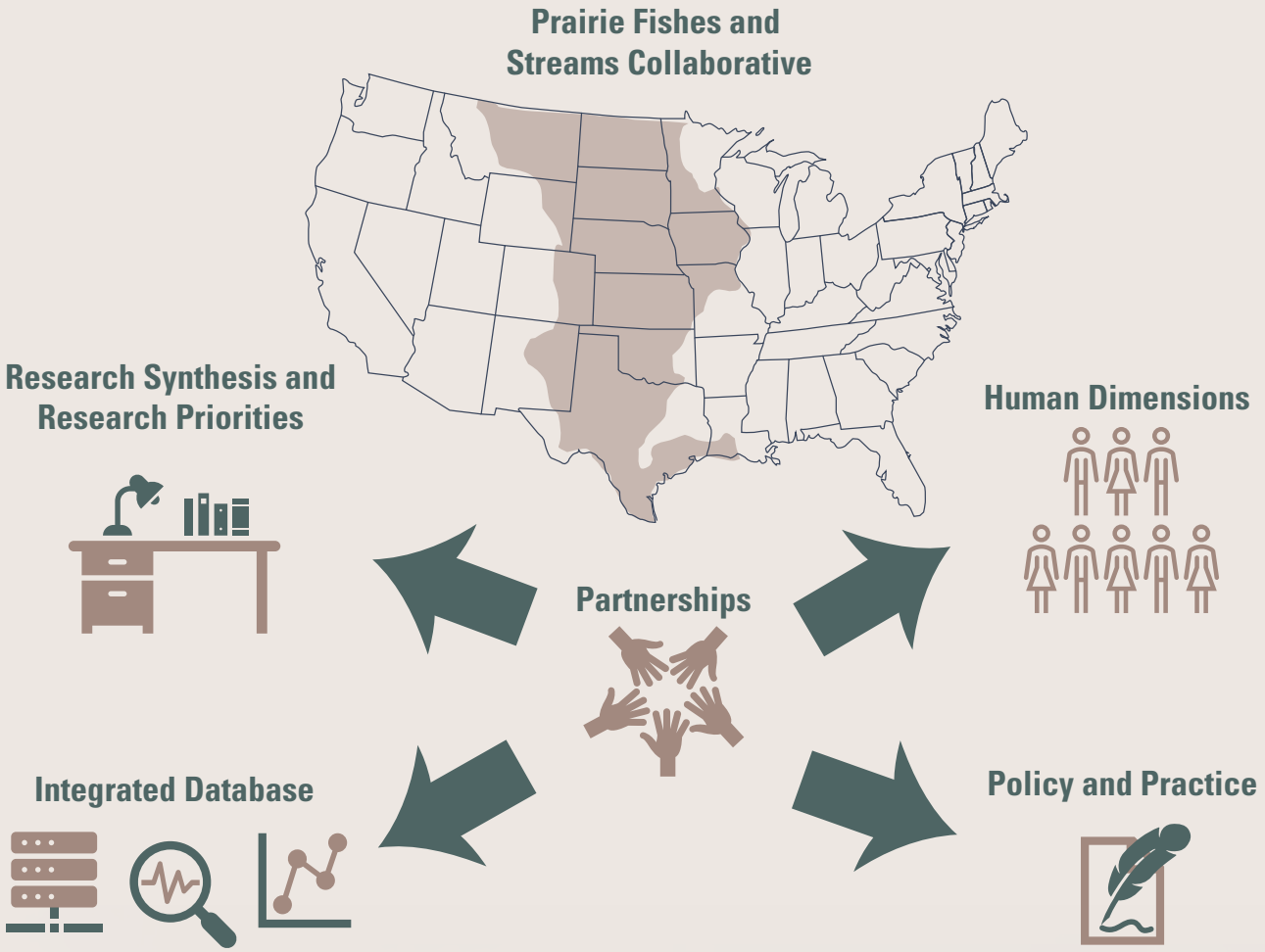


Figure 4. A graphical abstract of the Prairie Streams and Fishes Collaborative. The graphic illustrates the partnership's dimensions that include research synthesis, integrated database development, understanding human dimensions, and informing policy and practice for Prairie streams and fishes. A map of the continental United States indicates the region of interest to the collaborative (in tan/brown).

Snapshot USA

As natural areas continue to be developed and fragmented, the need for baseline data regarding the abundance and distribution of wildlife populations continues to grow. Snapshot USA is a project that is facilitating the collaboration of cooperators to contribute to a national database of public wildlife data; scientists from the Arkansas (B. DeGregorio) and Oklahoma (R. Lonsinger) CRUs are collaborators. In 2019, a network of scientists launched Snapshot USA (https://emammal.si.edu/snapshot-usa), a collaborative survey of terrestrial wildlife, using cameras across the United States. Surveys began in the fall of 2019 and data were collected at 1,509 camera sites within 110 camera arrays, covering 12 different ecoregions across all 50 States. In 2020, 1,485 individual cameras from 103 arrays resulted in 117,415 detections of 78 species of mammals and incidental detection of 43 species of birds. These data will be used to examine nationwide trends in mammal community assembly rules associated with natural environmental and anthropogenic filters. Collaborators from all 50 States have contributed camera trap data from a standardized camera trap array at the same time from each site. The principal investigators from the Smithsonian Conservation Biology Institute and North Carolina State University annually compile and lead efforts to analyze the data. Images are processed through the Smithsonian's eMammal data repository (2019) and Wildlife Insights (2020–22) and include an expert review to ensure taxonomic accuracy. All survey data were made available in a recent data publication (https://doi.org/10.1002/ecy.3775). Data collected will be archived at the Smithsonian and made available for local and macroecological research, including the examination of community assembly, effects of environmental and anthropogenic landscape variables, effects of fragmentation and extinction debt dynamics, as well as species-specific population dynamics and conservation action plans. Results will provide information regarding the occupancy of mesopredators (for example, raccoon *Procyon lotor*), activity patterns of animals nationwide, and relative density of several common species of mammals. This database is one of the largest repositories for images from camera traps and will provide the raw material for numerous large-scale ecological examinations of mammal populations.

Evaluating and Supporting Citizen Science

Worldwide, scientists are increasingly collaborating with the general public. Citizen science, or community science, has emerged as a cost-efficient method to collect data for wildlife and fisheries monitoring. CRU scientists are conducting research related to citizen science data quality, attitudes and characteristics of citizens engaged in data collection, and are even training citizens to collect and share data. Projects that citizens are helping with range from detection of birds (Utah Unit) and mammals (New York Unit), bighorn sheep respiratory disease (Iowa Unit), herring passage (Massachusetts Unit), jaguar (Panthera onca) and ocelots (Leopardus pardalis) (Arizona and New Mexico Units), to abundance of sea turtles (Minnesota Unit), standardized surveys of endangered mussels (Massachusetts Unit), and habitat characters of bumblebees (Utah Unit). These projects are engaging many citizens. For example, the New Mexico Unit's jaguar and ocelot monitoring project has more than 40 citizen science volunteers that have collected data since 2016, many of them are self-taught experts in large cat ecology. Citizen science data are being used in many research projects to build predictive models of species detection, distribution, and abundance to inform population and habitat management decisions for State and Federal cooperators.

Bobcat (*Lynx rufus*)

Jaguar (*Panthera onca*)

Applications of the Resist-Accept-Direct (RAD) Framework

As once familiar ecological conditions disappear, traditional management approaches that assume the future will reflect the past are becoming increasingly untenable. The resist-accept-direct (RAD) framework (fig. 5) encompasses the decision-space managers consider when addressing climate in local systems. To decide among strategies, managers must understand how specific systems are influenced by climate change. Several CRU scientists in Missouri (C. Paukert), New York (S. Sethi), and Wisconsin (D. Isermann and J. Homala) have been involved with development, delivery, and publication (Bioscience and Fisheries Management and Ecology) of decision-support systems using the RAD framework in collaboration with Federal, Tribal Nations, State, universities, NGO collaborators, as well as the USGS, CASCs, and multiple USGS science centers. The collective work was diverse and included placing adaptive management within the RAD framework to assist informed risk taking for transforming ecosystems, developing a decision-support tool for fishery management of walleye, presenting RAD strategies to address ecological goals for aquatic ecosystems and social goals for fisheries, and a case study of various inland fisheries to review management strategies for recreational and subsistence fisheries in response to climate change within the RAD framework. The collective work delivered decision-making tools and procedures from moving past resist strategies toward direct strategies using the RAD framework combined with other familiar frameworks, such as adaptive management.

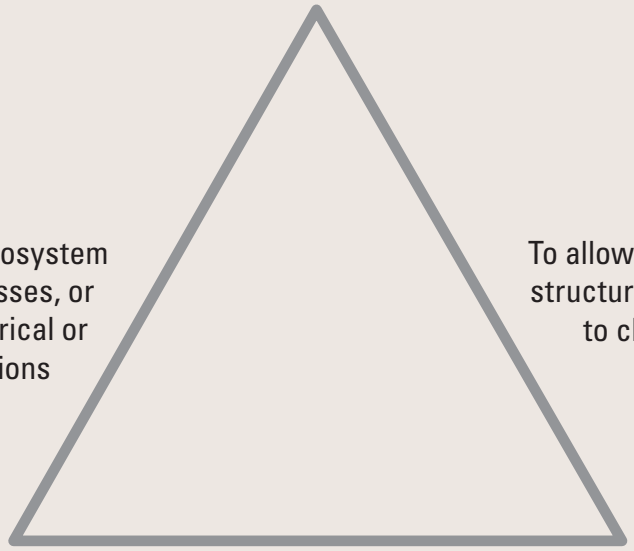


Figure 5. Diagram of the resist-accept-direct triangle (U.S. Geological Survey image).

Awards and Accolades

Annual CRU Awards

Craig P. Paukert, Unit Leader

Missouri Unit – Excellence in Science

Craig Paukert's research productivity in 2021 was outstanding, as was his support from unit cooperators. In addition, his mentorship of students and postdocs, as well as technical assistance to cooperators and other scientists will leave a lasting legacy for the CRU program and natural resources conservation. Craig's leadership in science and administration of the unit enables the two Assistant Unit Leaders (AULs) to succeed both scientifically and as graduate faculty. His research program has a strong affect to his cooperators and is focused on the highest regional, national, and international priorities.

Craig Paukert, Unit Leader of the Missouri CRU, holding a paddlefish from the Missouri River.

Allison K. Roy, Unit Leader

Massachusetts Unit – Excellence in Leadership

Allison Roy has demonstrated excellence in leadership in all aspects of her career and her professional conduct is a shining example of leadership within the CRUs. Allison has a distinguished record of scientific leadership in the development and implementation of large interdisciplinary research efforts of extraordinary scope and complexity. In addition, her mentorship of the AULs, as well as her students and postdocs, will leave a lasting legacy for the CRU program and natural resource conservation. In summary, Allison has exemplified leadership in all aspects of her career and professional conduct.

Allison Roy, Unit Leader of the Massachusetts Unit.

David C. Fulton, Assistant Unit Leader

Minnosota Unit – Excellence in Leadership

As the first human dimensions scientist hired in the CRU, David Fulton is a trailblazer, working through Federal regulations related to collecting information from the public and assisting other units in hiring scientists with expertise in human dimensions. David is highly regarded for his expertise, scientific contributions, and influence on policy. He has been instrumental in providing guidance to the CRU and incoming scientists regarding human dimensions research. Results of his collaborations with students and other colleagues have informed decision-makers and policy at the State, regional, national, and international levels. David has built and maintained productive relationships with Minnesota State and Federal cooperators and collaborators and has been a leader within the CRU in a discipline that has become more and more important to our cooperators and collaborators. David is highly deserving of the CRU Excellence in Leadership Award.

David Fulton, Assistant Unit Leader of the Minnesota Unit.

Awards and Scholarships

Unit Scientists

Aquatic Ecosystem Health and Management Society, Early Career Fellow
Andrew Carlson; Florida Unit

Fly Fishers International Conservation Award
James Long; Oklahoma Unit

AFS Fellow
Craig Paukert; Missouri Unit
Dan Isermann; Wisconsin Unit

AFS, Fisheries Management Section, Hall of Excellence
Dan Isermann; Wisconsin Unit

AFS, Emerging Leaders Mentorship Award
Christina Murphy; Maine Unit

AFS, North Central Division, Fisheries Excellence Award
Craig Paukert; Missouri Unit

USGS, Superior Service Award
Jeffrey Muehlbauer; Alaska Unit

Mississippi Chapter of the Wildlife Society, Sam K. Riffell Award for Conservation Excellence
Francisco Vilella; Mississippi Unit

Cornell University, Cornell Atkinson Center for Sustainability Fellow
Steve Grodsky; New York Unit

Auburn University, College of Agriculture Grantsmanship Award
Shannon Brewer; Alabama Unit

Tennessee Tech University, Wings Up Research Achievement
Amanda Rosenberger; Tennessee Unit
Mark Rogers; Tennessee Unit

Graduate Students and Postdoctoral Researchers

American Fisheries Society, J. Francis Allen Scholar, Runner-up
Hadley Boehm; Missouri Unit

The Wildlife Society, Donald H. Rusch Memorial Game Bird Research Scholarship
James Lee; New Mexico Unit

Atlantic States Marine Fisheries Commission, Award of Excellence
Brian Nuse; Georgia Unit

Missouri Chapter of the American Fisheries Society, Stephen A Weithman Jr. Leadership Award
Emily Tracy Smith; Missouri Unit

Conservation Federation of Missouri, Charles P. Bell Graduate Scholarship
Hadley Boehm; Missouri Unit

University of Florida, George Snow Scholarship
Bethany Gaffey; Florida Unit

University of Missouri, Trans World Airlines Scholarship
Gaby Ruso; Missouri Unit

Florida Chapter of the AFS, Roger Rottmann Memorial Scholarship
Tyler Coleman; Florida Unit

University of Florida, Doris and Earl Lowe and Verna Lowe Scholarship
Tyler Coleman; Florida Unit

Florida Wildlife Federation Scholarship
Tyler Coleman; Florida Unit

Chinook Salmon (*Oncorhynchus tshawytscha*)

University and State Cooperators

The Cooperative Fish and Wildlife Research Units program is a unique cooperative partnership among State fish and wildlife agencies, universities, WMI, USFWS, and USGS. The signed cooperating universities and State fish and wildlife agencies for each of the 42 units are listed below.

Alabama
Auburn University
Alabama Department of Conservation and Natural Resources

Alaska
University of Alaska Fairbanks
Alaska Department of Fish and Game

Arizona
University of Arizona
Arizona Game and Fish Commission

Arkansas
University of Arkansas
Arkansas Game and Fish Commission

California
Humboldt State University
California Department of Fish and Wildlife

Colorado
Colorado State University
Colorado Parks and Wildlife

Florida
University of Florida
Florida Fish and Wildlife Conservation Commission

Georgia
University of Georgia
Georgia Department of Natural Resources

Hawai‘i—Fishery
University of Hawai‘i
Hawai‘i Department of Land and Natural Resources

Idaho
University of Idaho
Idaho Department of Fish and Game

Iowa
Iowa State University
Iowa Department of Natural Resources

Kansas
Kansas State University
Kansas Department of Wildlife, Parks and Tourism

Louisiana
Louisiana State University
Louisiana Department of Wildlife and Fisheries

Maine
University of Maine
Maine Department of Inland Fisheries and Wildlife

Maryland
University of Maryland, Eastern Shore
Maryland Department of Natural Resources

Massachusetts
University of Massachusetts
Massachusetts Division of Fisheries and Wildlife
Massachusetts Division of Marine Fisheries

Michigan
Michigan State University
Michigan Department of Natural Resources

Minnesota
University of Minnesota
Minnesota Department of Natural Resources

Mississippi
Mississippi State University
Mississippi Department of Wildlife, Fisheries, and Parks

Missouri
University of Missouri Columbia
Missouri Department of Conservation

Montana—Fishery
Montana State University
Montana Department of Fish, Wildlife, and Parks

Montana—Wildlife
University of Montana
Montana Department of Fish, Wildlife, and Parks

Nebraska
University of Nebraska Lincoln
Nebraska Game and Parks Commission

Nevada
University of Nevada, Reno
Nevada Department of Wildlife

New Mexico
New Mexico State University
New Mexico Department of Game and Fish

New York
Cornell University
New York Department of Environmental Conservation

North Carolina
North Carolina State University
North Carolina Wildlife Resources Commission

Oklahoma
Oklahoma State University
Oklahoma Department of Wildlife Conservation

Oregon
Oregon State University
Oregon Department of Fish and Wildlife

Pennsylvania
Pennsylvania State University
Pennsylvania Fish and Boat Commission
Pennsylvania Game Commission

South Carolina
Clemson University
South Carolina Department of Natural Resources

South Dakota
South Dakota State University
South Dakota Department of Game, Fish, and Parks

Tennessee—Fishery
Tennessee Tech University
Tennessee Wildlife Resources Agency

Texas
Texas Tech University
Texas Parks and Wildlife Department

Utah
Utah State University
Utah Division of Wildlife Resources

Vermont
University of Vermont
Vermont Fish and Wildlife Department

Virginia
Virginia Polytechnic Institute and State University
Virginia Department of Game and Inland Fisheries

Washington
Washington State University
University of Washington
Washington Department of Ecology
Washington Department of Fish and Wildlife
Washington State Department of Natural Resources

West Virginia
West Virginia University
West Virginia Division of Natural Resources

Wisconsin—Fishery
University of Wisconsin Stevens Point
Wisconsin Department of Natural Resources

Wisconsin—Wildlife
University of Wisconsin Madison
Wisconsin Department of Natural Resources

Wyoming
University of Wyoming
Wyoming Game and Fish Commission

Photograph Credits

All photographs featured in this publication were taken by the U.S. Geological Survey except those for which credits are indicated in the list below.

p. iv-v, Flock of northern pintail flying over Yolo Bypass Wildlife Area. Photograph by Andrea Mott, USGS Western Ecological Research Center.

p. iii. Pronghorn (*Antilocapra americana*), U.S. Fish and Wildlife Service.

p. vi. Tidal marsh at sunset, U.S. Fish and Wildlife Service.

p. vii. Digger Bee (*Anthophorini*), U.S. Fish and Wildlife Service.

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p. 7. Alaska's Izembek National Wildlife Refuge, U.S. Fish and Wildlife Service.

p. 11. Gray wolves (*Canis lupus*) were reintroduced to Yellowstone National Park in 1995 and 1996. Photograph by Arthur Middleton, University of Wyoming.

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p. 18. Reintroduced Wyoming toad (*Anaxyrus baxteri*). Photograph by Mindy Meade, U.S. Fish and Wildlife Service.

p. 18. Plains spotted skunk (*Spilogale putorius*). Photograph by Paula Waggy.

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p. 21. Trojan male (MYY) brook trout (*Salvelinus fontinalis*) used as an eradication tool in New Mexico. Inset photograph by Michael Miller.

p. 22. Mexican Wolf (*Canis lupus bailey*), U.S. Fish and Wildlife Service.

p. 23. Sharptail-grouse (*Tympanuchus phasianellus*), U.S. Fish and Wildlife Service.

p. 24. Oklahoma reservoir. Photograph by Shannon Brewer

p. 25. Delta smelt sampling, U.S. Fish and Wildlife Service.

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p. 26. Moose (*Alces alces*), U.S. Fish and Wildlife Service.

p. 27. Black-capped petrel (*Pterodroma hasitata*), an endangered seabird, captured and fitted with a satellite tag. Photograph by Daniel J. Lebbin, American Bird Conservancy.

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p. 28. Pronghorn (*Antilocapra americana*) hunt in Wyoming. Photograph by Christine Williams

p. 29. Trout fishing, U.S. Fish and Wildlife Service.

p. 30. Left. Donovan Maude, University of Idaho graduate student, capturing white sturgeon (*Acipenser transmontanus*), Snake River, Idaho. Photograph by Michael Quist

p. 31. Mexican Wolf (*Canis lupus bailey*), U.S. Fish and Wildlife Service.

p. 34. Coastal marsh, U.S. Fish and Wildlife Service.

p. 37. Klamath River, U.S. Fish and Wildlife Service.

p. 38. Right inset. Coyote Canis latrans captured on a trail camera in Arkansas as part of Snapshot USA. Photograph provided by Brett DeGregorio

p. 38. Center. Citizen scientists, Liz Taylor and Tim Cook, checking for animal signs near camera traps for monitoring ocelot (*Leopardus pardalis*) and jaquar [(*Panthera onca*), left inset] populations in New Mexico. Photograph by Eline van Nes

p. 39. Folly Island, Maine. Photograph by Alex Demas.

p. 41. Chinook salmon (*Oncorhynchus tshawytscha*). Photograph by Ryan Hagerty, U.S. Fish and Wildlife Service.

p. 43. Fish Creek, Alaska, U.S. Fish and Wildlife Service.

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