COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./DUE DATE **NSF 19-593** **03/05/20**	☐ Special Exception to Deadline Date Policy	**FOR NSF USE ONLY** **NSF PROPOSAL NUMBER**
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.) **DEB - Long-Term Ecological Research**		

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN) **480771751**	SHOW PREVIOUS AWARD NO. IF THIS IS ☒ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL **1440484**	☐ ☒

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE
Kansas State University

AWARDEE ORGANIZATION CODE (IF KNOWN)
0019281000

ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE
Kansas State University
2 Fairchild Hall
Manhattan,KS.665061100

NAME OF PRIMARY PLACE OF PERF
Kansas State University

ADDRESS OF PRIMARY PLACE OF PERF, INCLUDING 9 DIGIT ZIP CODE
Kansas State University
Manhattan ,KS ,665061100 ,US.

IS AWARDEE ORGANIZATION (Check All That Apply) ☐ SMALL BUSINESS ☐ FOR-PROFIT ORGANIZATION ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS | ☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT **LTER: Manipulating drivers to assess grassland resilience**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ **7,122,000**	**72** months	**11/01/20**	

THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW
☐ BEGINNING INVESTIGATOR
☐ DISCLOSURE OF LOBBYING ACTIVITIES
☐ PROPRIETARY & PRIVILEGED INFORMATION
☐ HISTORIC PLACES
☒ VERTEBRATE ANIMALS IACUC App. Date **Planned**
PHS Animal Welfare Assurance Number **A3609-01**
☒ TYPE OF PROPOSAL **Research**
☐ HUMAN SUBJECTS Human Subjects Assurance Number ______
Exemption Subsection ______ or IRB App. Date ______
☐ FUNDING OF INT'L BRANCH CAMPUS OF U.S IHE ☐ FUNDING OF FOREIGN ORG
☐ INTERNATIONAL ACTIVITIES: COUNTRY/COUNTRIES INVOLVED
☒ COLLABORATIVE STATUS
A collaborative proposal from one organization (PAPPG II.D.3.a)

PI/PD DEPARTMENT
Division of Biology

PI/PD FAX NUMBER
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Direct for Biological Sciences
Division of Environmental Biology
Long-term Ecological Research

Proposal Classification Form
PI: Nippert, Jesse / Proposal Number: 2025849

CATEGORY I: INVESTIGATOR STATUS (Select ONE)

- ☐ Beginning Investigator - No previous Federal support as PI or Co-PI, excluding fellowships, dissertations, planning grants, etc.
- ☐ Prior Federal support only
- ☐ Current Federal support only
- ☑ Current & prior Federal support

CATEGORY II: FIELDS OF SCIENCE OTHER THAN BIOLOGY INVOLVED IN THIS RESEARCH (Select 1 to 3)

- ☐ Astronomy
- ☐ Chemistry
- ☐ Computer Science
- ☑ Geosciences
- ☐ Engineering
- ☐ Mathematics
- ☐ Physics
- ☐ Psychology
- ☐ Social Sciences
- ☐ None of the Above

CATEGORY III: SUBSTANTIVE AREA (Select 1 to 4)

- ☐ BIOGEOGRAPHY
- ☐ Island Biogeography
- ☐ Historical/ Evolutionary Biogeography
- ☐ Phylogeography
- ☐ Methods/Theory
- ☐ CHROMOSOME STUDIES
- ☐ Chromosome Evolution
- ☐ Chromosome Number
- ☐ Mutation
- ☐ Mitosis and Meiosis
- ☑ COMMUNITY ECOLOGY
- ☐ Community Analysis
- ☐ Community Structure
- ☐ Community Stability
- ☐ Succession
- ☐ Experimental Microcosms/ Mesocosms
- ☐ Disturbance
- ☐ Patch Dynamics
- ☐ Food Webs/ Trophic Structure
- ☐ Keystone Species
- ☐ COMPUTATIONAL BIOLOGY
- ☐ CONSERVATION & RESTORATION BIOLOGY
- ☑ DATABASES
- ☑ ECOSYSTEMS LEVEL
- ☐ Physical Structure
- ☐ Decomposition
- ☐ Biogeochemistry
- ☐ Limnology/Hydrology
- ☐ Climate/Microclimate
- ☐ Whole-System Analysis
- ☐ Productivity/Biomass
- ☐ System Energetics
- ☐ Landscape Dynamics
- ☐ Chemical & Biochemical Control
- ☐ Global Change
- ☐ Climate Change
- ☐ Regional Studies
- ☐ Global Studies
- ☐ Forestry
- ☐ Resource Management (Wildlife, Fisheries, Range, Other)
- ☐ Agricultural Ecology
- ☐ EXTREMOPHILES
- ☐ GENOMICS (Genome sequence, organization, function)
  - ☐ Viral
  - ☐ Microbial
  - ☐ Fungal
  - ☐ Plant
  - ☐ Animal
- ☐ MARINE MAMMALS
- ☐ MOLECULAR APPROACHES
- ☐ Molecular Evolution
- ☐ Methodology/Theory
- ☐ Isozymes/ Electrophoresis
- ☐ Nucleic Acid Analysis (general)
  - ☐ Restriction Enzymes
  - ☐ Nucleotide Sequencing
  - ☐ Nuclear DNA
  - ☐ Mitochondrial DNA
  - ☐ Chloroplast DNA
  - ☐ RNA Analysis
  - ☐ DNA Hybridization
  - ☐ Recombinant DNA
- ☐ Amino Acid Sequencing
- ☐ Gene/Genome Mapping
- ☐ Natural Products
- ☐ Serology/Immunology
- ☐ PALEONTOLOGY
- ☐ Floristic
- ☐ Faunistic
- ☐ Paleoecology
- ☐ Biostratigraphy
- ☐ Palynology
- ☐ Micropaleontology
- ☐ Paleoclimatology
- ☐ Archeozoic
- ☐ Paleozoic
- ☐ Mesozoic

☐ Cenozoic
☑ POPULATION DYNAMICS & LIFE HISTORY
☐ Demography/ Life History
☐ Population Cycles
☐ Distribution/Patchiness/ Marginal Populations
☐ Population Regulation
☐ Intraspecific Competition
☐ Reproductive Strategies
☐ Gender Allocation
☐ Metapopulations
☐ Extinction
☐ POPULATION GENETICS & BREEDING SYSTEMS
☐ Variation
☐ Microevolution
☐ Speciation
☐ Hybridization
☐ Inbreeding/Outbreeding
☐ Gene Flow Measurement
☐ Inheritance/Heritability

☐ Quantitative Genetics/ QTL Analysis
☐ Ecological Genetics
☐ Gender Ratios
☐ Apomixis/ Parthenogenesis
☐ Vegetative Reproduction
☐ SPECIES INTERACTIONS
☐ Predation
☐ Herbivory
☐ Omnivory
☐ Interspecific Competition
☐ Niche Relationships/ Resource Partititioning
☐ Pollination/ Seed Dispersal
☐ Parasitism
☐ Mutualism/ Commensalism
☐ Plant/Fungal/ Microbial Interactions
☐ Mimicry
☐ Animal Pathology
☐ Plant Pathology

☐ Coevolution
☐ Biological Control
☐ STATISTICS & MODELING
☐ Methods/ Instrumentation/ Software
☐ Modeling (general)
☐ Statistics (general)
  ☐ Multivariate Methods
  ☐ Spatial Statistics & Spatial Modeling
  ☐ Sampling Design & Analysis
  ☐ Experimental Design & Analysis
☐ SYSTEMATICS
☐ Taxonomy/Classification
☐ Nomenclature
☐ Monograph/Revision
☐ Phylogenetics
☐ Phenetics/Cladistics/ Numerical Taxonomy
☐ Macroevolution
☐ NONE OF THE ABOVE

CATEGORY IV: INFRASTRUCTURE (Select 1 to 3)

☐ COLLECTIONS/STOCK CULTURES
☐ Natural History Collections
☑ DATABASES
☐ FACILITIES
☐ Controlled Environment Facilities

☐ Field Stations
  ☐ Field Facility Structure
  ☐ Field Facility Equipment
☑ LTER Site
☐ INDUSTRY PARTICIPATION

☐ Technique Development
☐ TRACKING SYSTEMS
☐ Geographic Information Systems
☐ Remote Sensing
☐ NONE OF THE ABOVE

CATEGORY V: HABITAT (Select 1 to 2)

TERRESTRIAL HABITATS

☐ GENERAL TERRESTRIAL
☐ TUNDRA
☐ BOREAL FOREST
☐ TEMPERATE
  ☐ Deciduous Forest
  ☐ Coniferous Forest
  ☐ Rain Forest
  ☐ Mixed Forest
  ☑ Prairie/Grasslands
  ☐ Desert
☐ SUBTROPICAL
  ☐ Rain Forest
  ☐ Seasonal Forest
  ☐ Savanna
  ☐ Thornwoods
  ☐ Deciduous Forest
  ☐ Coniferous Forest
  ☐ Desert
☐ TROPICAL
  ☐ Rain Forest
  ☐ Seasonal Forest
  ☐ Savanna
  ☐ Thornwoods
  ☐ Deciduous Forest
  ☐ Coniferous Forest
  ☐ Desert

☐ CHAPPARAL/ SCLEROPHYLL/ SHRUBLANDS
☐ ALPINE
☐ MONTANE
☐ CLOUD FOREST
☐ RIPARIAN ZONES
☐ ISLANDS (except Barrier Islands)
☐ BEACHES/ DUNES/ SHORES/ BARRIER ISLANDS
☐ CAVES/ ROCK OUTCROPS/ CLIFFS
☐ CROPLANDS/ FALLOW FIELDS/ PASTURES
☐ URBAN/SUBURBAN
☐ SUBTERRANEAN/ SOIL/ SEDIMENTS
☐ EXTREME TERRESTRIAL ENVIRONMENT
☐ AERIAL

AQUATIC HABITATS

- ☐ GENERAL AQUATIC
- ☐ FRESHWATER
  - ☐ Wetlands/Bogs/Swamps
  - ☐ Lakes/Ponds
  - ☑ Rivers/Streams
  - ☐ Reservoirs
- ☐ MARINE
  - ☐ Open Ocean/Continental Shelf
  - ☐ Bathyal
  - ☐ Abyssal
  - ☐ Estuarine
  - ☐ Intertidal/Tidal/Coastal
  - ☐ Coral Reef
  - ☐ HYPERSALINE
- ☐ EXTREME AQUATIC ENVIRONMENT
- ☐ CAVES/ ROCK OUTCROPS/ CLIFFS
- ☐ MANGROVES
- ☐ SUBSURFACE WATERS/ SPRINGS
- ☐ EPHEMERAL POOLS & STREAMS
- ☐ MICROPOOLS (Pitcher Plants, Tree Holes, Other)

MAN-MADE ENVIRONMENTS

- ☐ LABORATORY
- ☐ THEORETICAL SYSTEMS
- ☐ OTHER ARTIFICIAL SYSTEMS

NOT APPLICABLE

- ☐ NOT APPLICABLE

CATEGORY VI: GEOGRAPHIC AREA OF THE RESEARCH (Select 1 to 2)

- ☐ WORLDWIDE
- ☑ NORTH AMERICA
  - ☐ United States
    - ☐ Northeast US (CT, MA, ME, NH, NJ, NY, PA, RI, VT)
    - ☐ Northcentral US (IA, IL, IN, MI, MN, ND, NE, OH, SD, WI)
    - ☐ Northwest US (ID, MT, OR, WA, WY)
    - ☐ Southeast US (DC, DE, FL, GA, MD, NC, SC, WV, VA)
    - ☑ Southcentral US (AL, AR, KS, KY, LA, MO, MS, OK, TN, TX)
    - ☐ Southwest US (AZ, CA, CO, NM, NV, UT)
    - ☐ Alaska
    - ☐ Hawaii
    - ☐ Puerto Rico
  - ☐ Canada
  - ☐ Mexico
- ☐ CENTRAL AMERICA (Mainland)
  - ☐ Caribbean Islands
  - ☐ Bermuda/Bahamas
- ☐ SOUTH AMERICA
  - ☐ Eastern South America (Guyana, Fr. Guiana, Suriname, Brazil)
  - ☐ Northern South America (Colombia, Venezuela)
  - ☐ Southern South America (Chile, Argentina, Uruguay, Paraguay)
  - ☐ Western South America (Ecuador, Peru, Bolivia)
- ☐ EUROPE
  - ☐ Eastern Europe
  - ☐ Russia
  - ☐ Scandinavia
  - ☐ Western Europe
- ☐ ASIA
  - ☐ Central Asia
  - ☐ Far East
  - ☐ Middle East
  - ☐ Siberia
  - ☐ South Asia
  - ☐ Southeast Asia
- ☐ AFRICA
  - ☐ North Africa
  - ☐ African South of the Sahara
    - ☐ East Africa
    - ☐ Madagascar
    - ☐ South Africa
    - ☐ West Africa
- ☐ AUSTRALASIA
  - ☐ Australia
  - ☐ New Zealand
  - ☐ Pacific Islands
- ☐ ANTARCTICA
- ☐ ARCTIC
- ☐ ATLANTIC OCEAN
- ☐ PACIFIC OCEAN
- ☐ INDIAN OCEAN
- ☐ OTHER REGIONS (Not defined)
- ☐ NOT APPLICABLE

CATEGORY VII: CLASSIFICATION OF ORGANISMS (Select 1 to 4)

- ☐ VIRUSES
  - ☐ Bacterial
  - ☐ Plant
  - ☐ Animal
- ☐ PROKARYOTES
  - ☐ Archaea
  - ☐ Cyanobacteria
  - ☐ Bacteria
  - ☐ Noncultured Organisms
- ☐ PROTISTA (PROTOZOA)
  - ☐ Amoebae
  - ☐ Apicomplexa
  - ☐ Ciliophora
  - ☐ Flagellates
  - ☐ Foraminifera
  - ☐ Microspora
  - ☐ Radiolaria
- ☐ FUNGI
  - ☐ Ascomycota
  - ☐ Basidiomycota
  - ☐ Chytridiomycota
  - ☐ Mitosporic Fungi
  - ☐ Oomycota
  - ☐ Zygomycota
- ☐ LICHENS
- ☐ SLIME MOLDS
- ☐ ALGAE
  - ☐ Bacillariophyta (Diatoms)
  - ☐ Charophyta
  - ☐ Chlorophyta
  - ☐ Chrysophyta
  - ☐ Dinoflagellata
  - ☐ Euglenoids
  - ☐ Phaeophyta
  - ☐ Rhodophyta
- ☐ PLANTS
  - ☐ NON-VASCULAR PLANTS
    - ☐ BRYOPHYTA
      - ☐ Anthocerotae (Hornworts)
      - ☐ Hepaticae (Liverworts)
      - ☐ Musci (Mosses)
  - ☑ VASCULAR PLANTS
    - ☐ FERNS & FERN ALLIES
    - ☐ GYMNOSPERMS
      - ☐ Coniferales (Conifers)

- ☐ Cycadales (Cycads)
- ☐ Ginkgoales (Ginkgo)
- ☐ Gnetales (Gnetophytes)
- ☐ ANGIOSPERMS
  - ☐ Monocots
    - ☐ Arecaceae (Palmae)
    - ☐ Cyperaceae
    - ☐ Liliaceae
    - ☐ Orchidaceae
    - ☐ Poaceae (Graminae)
  - ☐ Dicots
    - ☐ Apiaceae (Umbelliferae)
    - ☐ Asteraceae (Compositae)
    - ☐ Brassicaceae (Cruciferae)
    - ☐ Fabaceae (Leguminosae)
    - ☐ Lamiaceae (Labiatae)
    - ☐ Rosaceae
    - ☐ Solanaceae

- ☐ ANIMALS
  - ☑ INVERTEBRATES
    - ☐ MESOZOA/PLACOZOA
    - ☐ PORIFERA (Sponges)
    - ☐ CNIDARIA
      - ☐ Hydrozoa (Hydra, etc.)
      - ☐ Scyphozoa (Jellyfish)
      - ☐ Anthozoa (Corals, Sea Anemones)
    - ☐ CTENOPHORA (Comb Jellies)
    - ☐ PLATYHELMINTHES (Flatworms)
      - ☐ Turbellaria (Planarians)
      - ☐ Trematoda (Flukes)
      - ☐ Cestoda (Tapeworms)
      - ☐ Monogenea (Flukes)
    - ☐ GNATHOSTOMULIDA
    - ☐ NEMERTINEA (Rynchocoela) (Ribbon Worms)
    - ☐ ENTOPROCTA (Bryozoa) (Plant-like Animals)
    - ☐ ASCHELMINTHES
      - ☐ Gastrotricha
      - ☐ Kinorhyncha
      - ☐ Loricifera
      - ☐ Nematoda (Roundworms)
      - ☐ Nematomorpha (Horsehair Worms)
      - ☐ Rotifera (Rotatoria)
    - ☐ ACANTHOCEPHALA (Spiny-headed Worms)
    - ☐ PRIAPULOIDEA
    - ☐ BRYOZOA (Ectoprocta) (Plant-like Animals)
    - ☐ PHORONIDEA (Lophophorates)
    - ☐ BRACHIOPODA (Lamp Shells)
    - ☐ MOLLUSCA
      - ☐ Monoplacophora
      - ☐ Aplacophora (Solenogasters)
      - ☐ Polyplacophora (Chitons)
      - ☐ Scaphopoda (Tooth Shells)
      - ☐ Gastropoda (Snails, Slugs, Limpets)
      - ☐ Pelecypoda (Bivalvia) (Clams, Mussels, Oysters, Scallops)
      - ☐ Cephalopoda (Squid, Octopus, Nautilus)
    - ☐ ANNELIDA (Segmented Worms)
      - ☐ Polychaeta (Parapodial Worms)
      - ☐ Oligochaeta (Earthworms)
      - ☐ Hirudinida (Leeches)
    - ☐ POGONOPHORA (Beard Worms)
    - ☐ SIPUNCULOIDEA (Peanut Worms)
    - ☐ ECHIUROIDEA (Spoon Worms)
    - ☐ ARTHROPODA
      - ☐ Cheliceriformes
        - ☐ Merostomata (Horseshoe Crabs)
        - ☐ Pycnogonida (Sea Spiders)
        - ☐ Scorpionida (Scorpions)
        - ☐ Araneae (True Spiders)
        - ☐ Pseudoscorpionida (Pseudoscorpions)
        - ☐ Acarina (Free-living Mites)
        - ☐ Parasitiformes (Parasitic Ticks & Mites)
      - ☐ Crustacea
        - ☐ Branchiopoda (Fairy Shrimp, Water Flea)
        - ☐ Ostracoda (Sea Lice)
        - ☐ Copepoda
        - ☐ Cirripedia (Barnacles)
        - ☐ Amphipoda (Skeleton Shrimp, Whale Lice, Freshwater Shrimp)
        - ☐ Isopoda (Wood Lice, Pillbugs)
        - ☐ Decapoda (Lobster, Crayfish, Crabs, Shrimp)
      - ☐ Hexapoda (Insecta) (Insects)
        - ☐ Apterygota (Springtails, Silverfish, etc.)
        - ☐ Odonata (Dragonflies, Damselflies)
        - ☐ Ephemeroptera (Mayflies)
        - ☐ Orthoptera (Grasshoppers, Crickets)
        - ☐ Dictyoptera (Cockroaches, Mantids, Phasmids)
        - ☐ Isoptera (Termites)
        - ☐ Plecoptera (Stoneflies)
        - ☐ Phthiraptera (Mallophaga & Anoplura) (Lice)
        - ☐ Hemiptera (including Heteroptera) (True Bugs)
        - ☐ Homoptera (Cicadas, Scale Insects, Leafhoppers)
        - ☐ Thysanoptera (Thrips)
        - ☐ Neuroptera (Lacewings, Dobsonflies, Snakeflies)
        - ☐ Trichoptera (Caddisflies)
        - ☐ Lepidoptera (Moths, Butterflies)
        - ☐ Diptera (Flies, Mosquitoes)
        - ☐ Siphonaptera (Fleas)
        - ☐ Coleoptera (Beetles)
        - ☐ Hymenoptera (Ants, Bees, Wasps, Sawflies)
      - ☐ Chilopoda (Centipedes)
      - ☐ Diplopoda (Millipedes)
      - ☐ Pauropoda
      - ☐ Symphyta (Symphyla)
    - ☐ PENTASTOMIDA (Linguatulida) (Tongue Worms)
    - ☐ TARDIGRADA (Tardigrades, Water Bears)
    - ☐ ONYCHOPHORA (Peripatus)
    - ☐ CHAETOGNATHA (Arrow Worms)
    - ☐ ECHINODERMATA
      - ☐ Crinoidea (Sea Lilies, Feather Stars)
      - ☐ Asteroidea (Starfish, Sea Stars)
      - ☐ Ophiuroidea (Brittle Stars, Serpent Stars)
      - ☐ Echinoidea (Sea Urchins, Sand Dollars)
      - ☐ Holothuroidea (Sea Cucumbers)
    - ☐ HEMICHORDATA (Acorn Worms, Pterobranchs)
    - ☐ UROCHORDATA (Tunicata) (Tunicates, Sea Squirts, Salps, Ascideans)
    - ☐ CEPHALOCHORDATA (Amphioxus/Lancelet)
  - ☐ VERTEBRATES
    - ☐ AGNATHA (Hagfish, Lamprey)
    - ☐ FISHES
      - ☐ Chondrichthyes (Cartilaginous Fishes) (Sharks, Rays, Ratfish)
      - ☐ Osteichthyes (Bony Fishes)
    - ☐ AMPHIBIA
      - ☐ Anura (Frogs, Toads)
      - ☐ Urodela (Salamanders, Newts)
      - ☐ Gymnophiona (Apoda) (Caecilians)
    - ☐ REPTILIA
      - ☐ Chelonia (Turtles, Tortoises)
      - ☐ Serpentes (Snakes)
      - ☐ Sauria (Lizards)
      - ☐ Crocodylia (Crocodilians)
    - ☑ AVES (Birds)
      - ☐ Passeriformes (Passerines)
    - ☑ MAMMALIA
      - ☐ Monotremata (Platypus, Echidna)
      - ☐ Marsupalia (Marsupials)
      - ☐ Eutheria (Placentals)
        - ☐ Insectivora (Hedgehogs, Moles, Shrews, Tenrec, etc.)
        - ☐ Chiroptera (Bats)
        - ☐ Primates
          - ☐ Humans
        - ☐ Rodentia
        - ☐ Lagomorphs (Rabbits, Hares, Pikas)
        - ☐ Carnivora (Bears, Canids, Felids, Mustelids, Viverrids, Hyena, Procyonids)
          - ☐ Perissodactyla (Odd-toed Ungulates) (Horses, Rhinos, Tapirs, etc.)

☐ Artiodactyla (Even-toed Ungulates) (Cattle, Sheep, Deer, Pigs, etc.) ☐ Marine Mammals (Seals, Walrus, Whales, Otters, Dolphins, Porpoises)	☐ TRANSGENIC ORGANISMS ☐ FOSSIL OR EXTINCT ORGANISMS	☐ NO ORGANISMS

CATEGORY VIII: MODEL ORGANISM (Select ONE)

☑ NO MODEL ORGANISM MODEL ORGANISM (Choose from the list)	☐ Escherichia coli ☐ Mouse-Ear Cress (Arabidopsis thaliana)	☐ Fruitfly (Drosophila melanogaster)

PROJECT SUMMARY

Overview:

The Konza Prairie LTER program (KNZ) focuses on the ecological dynamics of tallgrass prairie - a historically widespread mesic grassland in the North American Great Plains. Our core research site is the Konza Prairie Biological Station (KPBS), a 3487 ha native tallgrass prairie located in the Flint Hills of northeast Kansas, USA. Since 1980, KNZ has investigated how key drivers of grasslands globally - fire, grazing, and climatic variability - interact to influence tallgrass prairie structure and function. The conceptual framework of KNZ LTER VIII builds on long-term studies, reflects the increasing complexity of research questions developed over the history of this program, and explicitly recognizes that tallgrass prairie pattern and process results from human alteration of ecological drivers at local (e.g., land use and management), regional (e.g., nutrient inputs) and global (e.g., climate change) scales. Our research will provide new information critical for understanding, managing, and conserving grasslands globally, while concurrently addressing fundamental ecological questions to explain grassland dynamics in a changing world.

Intellectual Merit:

KNZ utilizes long-term, watershed-scale manipulations of fire frequency and grazing by large ungulates, coupled with numerous plot-scale manipulations (i.e., nutrients and rainfall) to test ecological theory and address timely questions regarding grassland responses to multiple, interacting global changes. KNZ LTER VIII builds upon a legacy of long-term observations and experiments manipulating key drivers to assess changes in the structure and function of tallgrass prairie and associated dynamics in aquatic systems. A recurring theme from prior KNZ research is that grassland responses to variation in ecological drivers vary in magnitude and change dynamically over time. Long-term studies are required to improve our ability to forecast change in this ecosystem, identify the mechanisms that facilitate and reinforce these ecological changes, and determine if the ecological changes we have observed are reversible. LTER VII began our focus on mechanisms that underlie the sensitivity and resilience of ecosystem states in mesic grasslands. LTER VIII will utilize the array of ecosystem states that have emerged from these manipulations of historical and global change drivers to refine our understanding of sensitivity, resilience, and ecosystem state change in tallgrass prairie. To accomplish this, our proposed research comprises four thematic areas: 1) continued watershed-level manipulations of historical drivers (fire and grazing), 2) experimental manipulations of global change drivers, 3) cessation or reversal of selected drivers to assess legacies, and 4) human intervention. Collectively, new KNZ research will advance ecological theory and improve our mechanistic understanding of ecosystem state changes by manipulating key drivers to alter ecological states while employing new analytical approaches to augment the value of our long-term data sets.

Broader Impacts:

The KNZ LTER program will continue to benefit society in many ways, including educating and training students from K-12 through postgraduate, performing public outreach, engaging artists in art-science interactions, and fostering a diverse scientific community. The Konza Environmental Education Program provides activities that engage K-12 students and teachers with ecological data collection and interpretation of tallgrass prairie ecology. KNZ provides meaningful educational and research opportunities for undergraduates via participation in core LTER data collection, independent research with faculty advisers, and summer REU internships. During KNZ LTER VIII we will develop additional research opportunities for undergraduates at Haskell Indian Nations University. KNZ provides research opportunities for numerous graduate students (from >10 universities) and provides support in the form of stipends, on-site assistance, equipment, and travel support. KNZ investigators and students will continue to participate in activities that link ecology with art, will host artists-in-residence on site, and partner with a local art museum to promote human engagement with a regionally important landscape. Finally, KNZ experiments will inform natural resource management and conservation. Tests of ecological theory relevant to grassland restoration will be used to develop more effective restoration approaches, and inform conservation and restoration goals in grasslands experiencing landscape and associated global changes.

Project Description: *KNZ LTER VIII: Manipulating drivers to assess grassland resilience*

I. OVERVIEW

The Konza Prairie LTER program (KNZ) studies the ecological dynamics of a historically widespread, but currently imperiled, mesic grassland in the North American Great Plains: *the tallgrass prairie*. **Our central focus is understanding how three key drivers of grasslands -- fire, grazing, and climatic variability -- interact to affect tallgrass prairie structure and function** (Figs. 1 & 2). KNZ scientists conduct research critical for understanding, managing, and conserving tallgrass prairies and other grasslands globally, while concurrently addressing fundamental ecological questions that transcend site-level research. In 1980, KNZ research began with a unique watershed-scale fire experimental design that was expanded over seven LTER cycles to include ungulate grazing, short- and long-term plot-level, stream-reach and restoration experiments, and a network of terrestrial and aquatic sensors and sampling stations (Fig. 3). Insights from a diverse array of long-term observations and experiments have provided a multifaceted and detailed understanding of how fire, grazing, climatic variability, and a suite of global drivers interact to influence the dynamics of tallgrass prairie and associated aquatic systems (Fig. 2; see *Prior Support*). A recurring theme from KNZ research is that responses to ecological drivers are highly variable in magnitude and temporal dynamics, and specific combinations of change - some linear and some non-linear - can lead to different ecosystem states. The inherent variability within this ecosystem highlights the need for long-term studies to: (i) increase our understanding of ecological responses to future changes in key drivers, (ii) identify the mechanisms that promote and reinforce these changes, and (iii) determine if the ecological changes we have observed are reversible.

The KNZ program harnesses a unique combination of long-term watershed- and shorter-term plot-level experiments that manipulate historical ecological drivers and contemporary global change drivers (Fig. 3). This varied experimental landscape provides exceptional opportunities to address the temporal dynamics and mechanisms of tallgrass prairie sensitivity and ecosystem state change (terms defined in Box 1). At the start of the KNZ program, terrestrial and aquatic systems reflected a relatively uniform history of grazing and fire management (Fig. 4). Four decades of experimentally imposed factorial combinations of fire and grazing initiated in LTER I-III, coupled with >20 nutrient, climate, and restoration experiments during LTER VI-VII, have resulted in <u>a variety of ecosystem states on the landscape with known antecedent legacies</u> (Fig. 4). Of note, the ecosystem states at KNZ reflect land cover changes occurring worldwide (Sohl *et al*. 2012).

The overarching goal of LTER VIII is to leverage manipulations of historical and global change drivers at KNZ, which have produced an array of ecosystem states, to evaluate the mechanisms that underlie sensitivity and resilience in tallgrass prairie (Box 1). To accomplish this, our proposed research comprises four thematic areas: 1) watershed-level study of the long-term effects of historical drivers (fire and grazing), 2) experimental manipulations of global change drivers, 3) cessation or reversal of selected drivers, and 4) human intervention (study locations shown in Fig. 3). Collectively, we will use ongoing and new activities under each theme to assess ecosystem sensitivity

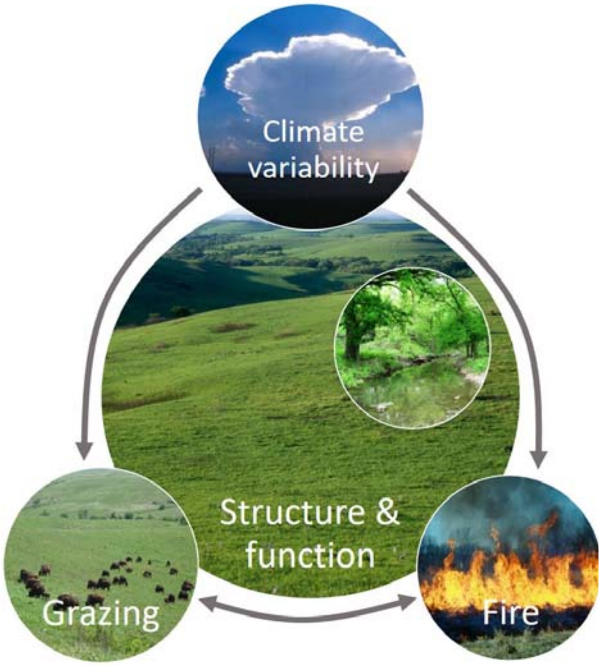

Fig. 1: The structure and function of terrestrial and aquatic (inset) systems at KNZ reflects long-term responses to fire and grazing, and their interactions with a variable climate.

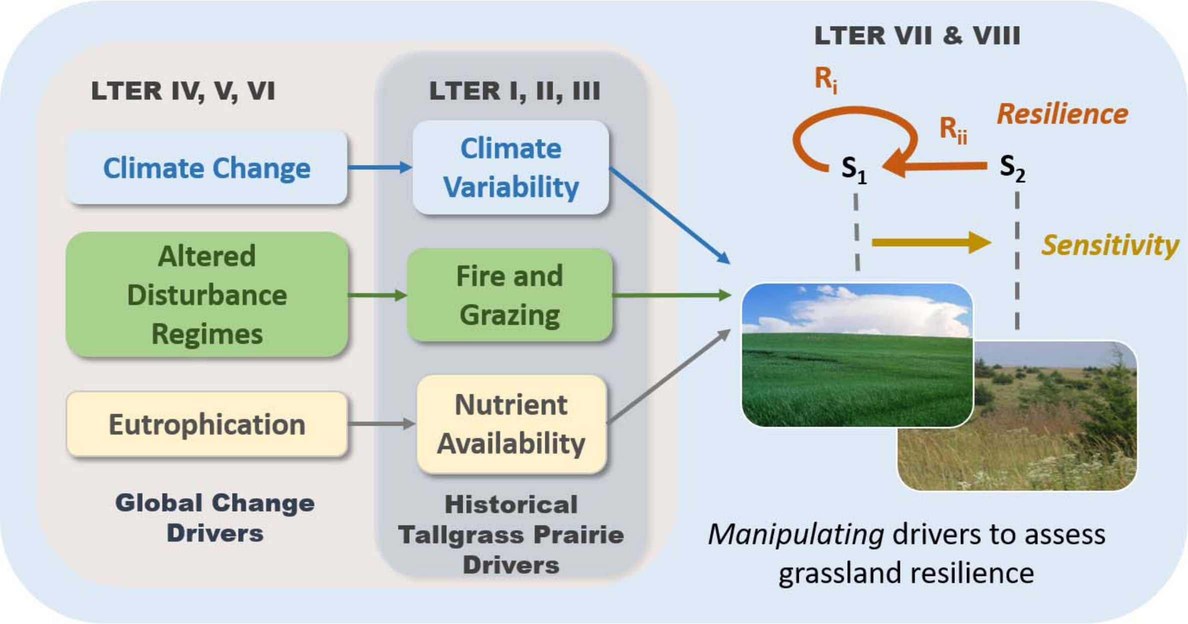

Fig. 2: The conceptual framework for **KNZ LTER VIII** builds upon the legacies of KNZ research investigating fire, grazing, climate variability, and nutrient availability (**LTER I-III**) and the consequences of global change (**LTER IV-VI**) as drivers of tallgrass prairie ecosystem dynamics. During **LTER VII**, we began investigating the mechanisms that underlie sensitivity and resilience to alterations in grassland drivers. **The LTER VIII conceptual framework** integrates the increasing complexity of our LTER objectives over time and recognizes that the key determinants of pattern and processes in grasslands are directly (land use and management) and indirectly (climate change and nutrient inputs) determined by human activities. Manipulation of drivers allow us to assess sensitivity, transitions between states (S_1, S_2), and the potential for recovery and/or changes in resilience (R_i, R_{ii}). See Box 1 for definitions of terms.

and resilience through the manipulation or restoration of drivers or ecosystem states. We will: 1) conduct targeted investigations of mechanisms that underlie ecosystem sensitivity and state change as informed by results to date, 2) interpret experiments in the context of long-term observations at KNZ (Knapp *et al.* 2018, Bruckerhoff *et al.* 2020, Smith *et al.* 2020) and in comparison to other grasslands and biomes (e.g., Smith *et al.* 2016, Koerner *et al.* 2018, Komatsu *et al.* 2019), 3) advance general ecological theory and inform theoretical and process-based ecological models (Smith *et al*. 2009, Dodds *et al*. 2015, Ratajczak *et al.* 2017b, Brunsell *et al.* 2017, Ratajczak *et al.* 2018), and 4) maximize the broader impacts of our research by providing full open access to all core datasets, applying insights from KNZ research to management, conservation, and restoration of grasslands, while expanding KNZ education and public outreach programs.

Box 1: Key Terms Defined

Concept	**Definition**
State (S_i)	Quantifiable characteristics of an ecosystem in a particular place and/or point in time
Sensitivity	Responsiveness of a state to a change in drivers (Knapp *et al.* 2015); the inverse of resistance
Resilience (R_i, R_{ii})	The ability to maintain a qualitatively similar state over time (Walker *et al.* 2004). Resilience is achieved by: (R_i) resisting changes in drivers or disturbance and/or (R_{ii}) returning to an initial state (i.e., recovery) following some period of time (bouncing back in the absence of resistance) (following Ratajczak *et al.* 2018)
Legacy effects	Characteristics of a system that developed under particular ecological drivers, which continue to affect state dynamics when those drivers are ceased or reversed (Sala *et al.* 2012, Johnstone *et al.* 2016)

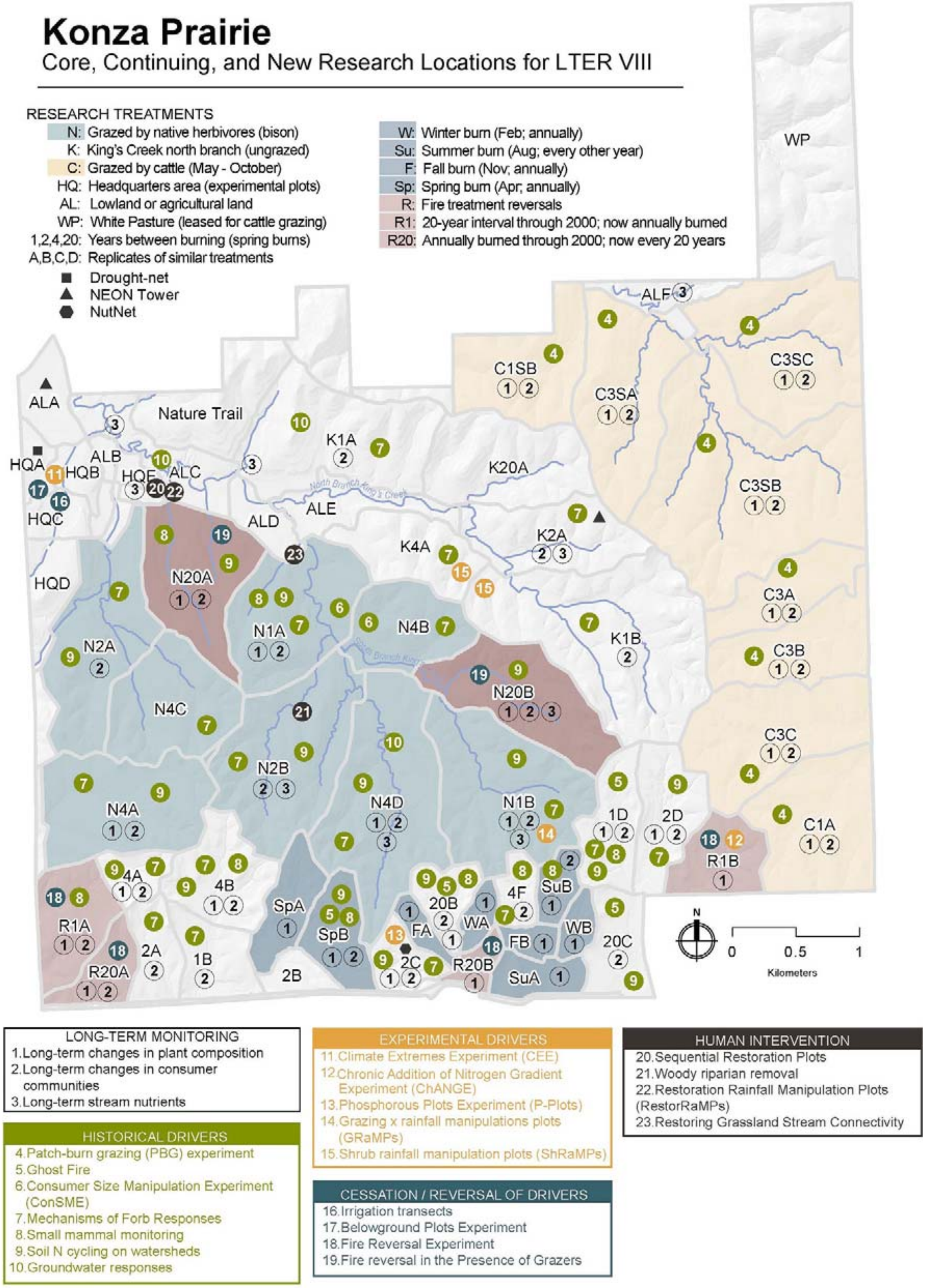

Fig. 3: The Konza Prairie site-based watershed-level experimental design. Watershed boundaries are denoted by grey lines, and watershed IDs indicate research treatments. Unless specified, prescribed fires occur during Spring (Mar-Apr). Numbered circles identify locations corresponding with projects described in Section VI, with colors indicating the 4 research themes.

Intellectual Merit
II. BACKGROUND

Study System: Tallgrass Prairie – Grassland covers approximately ~40% of Earth's land surface (Asner *et al.* 2004, Dixon *et al.* 2014) and accounts for 20-25% of terrestrial productivity (Still *et al.* 2003) and 18% of global runoff (Dodds *et al.* 2015). Temperate grasslands are a major ecosystem type in North America, with the Great Plains (2.17 million km^2) representing the second largest grassland ecoregion in the world (Dixon *et al.* 2014). Tallgrass prairie is the most productive and diverse grassland type in the Great Plains (Searchinger *et al.* 2015), and occurs where annual precipitation often equals annual evapotranspiration. Over the 19th and 20th centuries, most of the tallgrass prairie was cultivated for cropland agriculture (Sampson & Knopf 1994), and humans extirpated a substantial portion of the mega-fauna (e.g., bison, elk). A pervasive threat to remaining tallgrass prairie is woody plant encroachment — the conversion of grassland to shrub and/or tree dominated states — caused by too infrequent and less intense fires, landscape fragmentation that impedes fire spread, and increased propagule pressure by woody species potentially influenced by increased atmospheric [CO_2] (Higgins & Scheiter 2012, Ratajczak *et al.* 2014b, 2016, Brunsell *et al.* 2017, Scholtz *et al.* 2018).

KNZ LTER research is based at the Konza Prairie Biological Station (KPBS), a 3487 ha native tallgrass prairie preserve in the Flint Hills ecoregion of Kansas, USA. The Flint Hills contains the largest area of unplowed tallgrass prairie in North America (Sampson & Knopf 1994). The flora of KPBS is dominated by perennial C_4 grasses (*Andropogon gerardii, Schizachyrium scoparium, Panicum virgatum,* and *Sorghastrum nutans*), but is highly diverse with >700 vascular grass, forb, and woody species (Collins & Calabrese 2012, Taylor *et al.* unpublished). The climate is mid-continental with cold, dry winters (-7.09 ºC mean min temp in Jan [1982-2019]) and warm, wet summers (32.70 ºC mean max temp in July [1982-2019]). Long-term mean annual precipitation for KNZ is 835 mm (1982-2019), of which 75% occurs during the April-September growing season. Reduced evaporation and transpiration in winter (November-March) allows a greater portion of precipitation to recharge deep soil moisture and groundwater.

The topography of KPBS is characteristic of the Flint Hills region (Figs. 1, 3), with steep hillslopes and ca. 100 m relief between uplands, with relatively shallow soils (~30 cm depth), and lowlands with soils > 2 m depth (Ransom *et al.* 1998). Topography, which has figured significantly in KNZ research strongly influences plant community composition and ecosystem processes (Nippert *et al.* 2011). This complex topography is a product of the erosion of limestone bedrock and mudstone layers that formed beneath a vast ancient ocean. Weathering of these geologic layers results in a merokarst system characterized by fractures, joints, and perched aquifers (Macpherson & Sullivan 2019), as well as a complex network of high and low hydraulic conductivity and variable subsurface water infiltration and flow (Vero *et al.* 2018). The Kings Creek watershed is completely contained within KPBS and includes a perennial downstream reach, intermittent and ephemeral middle and upper reaches, and some perennial springs (Fig. 3). Shallow groundwater tables (~5.5 m depth) connect to Kings Creek, resulting in rapid water table responses to precipitation (Macpherson *et al.* 2008; Macpherson *et al.* 2019). This hydrology underlies the heterogeneity in nutrient export from the watersheds (Rüegg *et al.* 2015) and sets a template of high abiotic variability for stream biota (Dodds *et al.* 2004, Bruckerhoff *et al.* 2020).

Core watershed-scale research on KNZ focuses on the role of fire, grazing, and climate on ecosystem structure and function (Knapp *et al.* 1998). The central experimental platform includes replicate watersheds varying in fire frequency (1, 2, 4, and 20-yr fire return intervals, including treatment reversals), with or without grazing by bison or cattle (Fig. 3). Bison were re-introduced in 1987 and graze year-round within a >1000 ha area encompassing replicate watersheds of the four fire frequencies. A comparison of cattle and bison grazing began in 1992. In 2010, we initiated a patch-burn grazing experiment to evaluate the role of fire-mediated rotational grazing on dual goals of cattle production and biodiversity conservation. This management strategy, used by local ranchers and advocated by *The Nature Conservancy*, aims to maximize prairie plant and animal diversity by creating landscape heterogeneity through a shifting mosaic of fire-induced grazer movements (Fuhlendorf *et al.* 2009). While spring fires are most common (Hulbert 1973), winter, spring and summer burn watersheds were established in 1994, because fires started by lightning can occur year-round (Hulbert 1973).

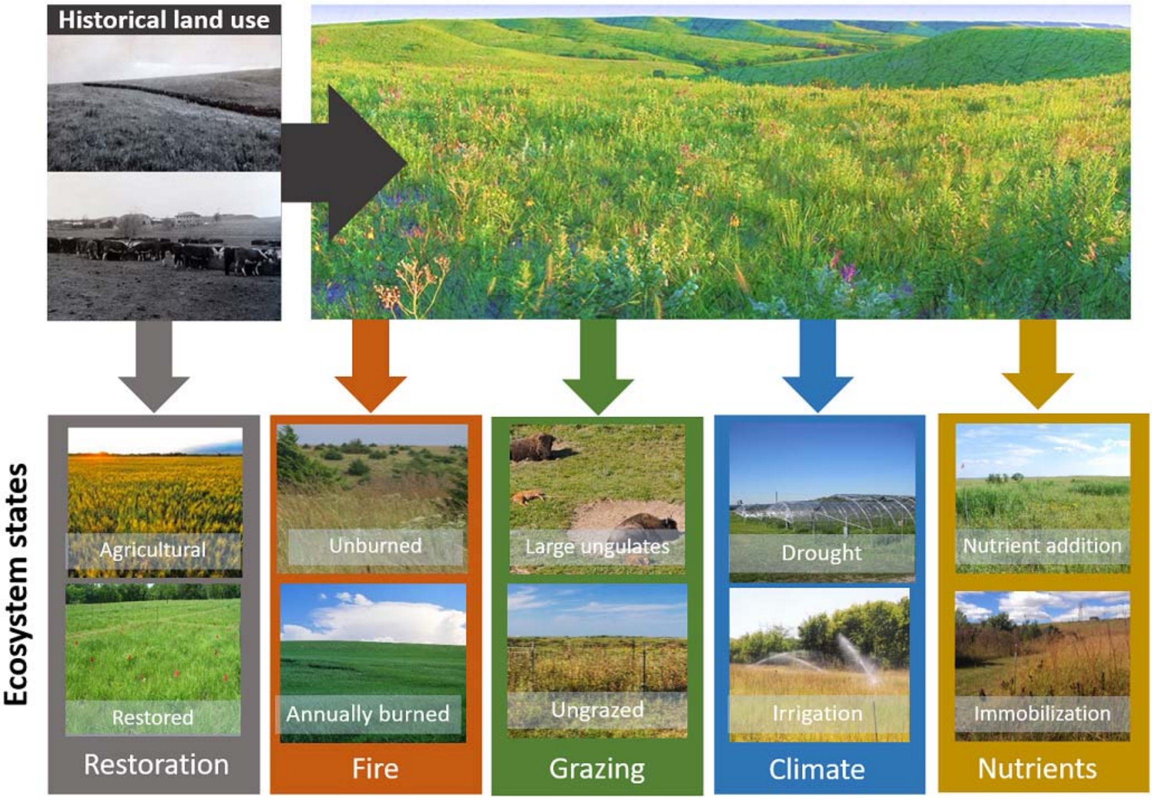

Fig. 4: The KPBS landscape contains a mosaic of ecosystem states (depicted in the pictures) resulting from the manipulation of an array of historically important and contemporary drivers.

History of KNZ Research – During **LTER I-III (1980-1996)**, we initiated studies of the major abiotic (climate, fire, nutrients, topoedaphic gradients, hydrology) and biotic (herbivory, competition, mutualism) factors affecting mesic grasslands, which led to a dynamic, non-equilibrium perspective of ecological pattern and process in tallgrass prairie (Knapp *et al.* 1998). Long-term sampling sites and protocols were established, spatial scales of inquiry increased, and an emphasis on grassland streams and belowground processes emerged. Bison were re-introduced in 1987 to explore how grazing interacts with the landscape mosaic produced under different fire regimes. Also during this time, we began to investigate the role of climate variability on grassland productivity. **LTER IV (1996-2002)** initiated new long-term experiments on grassland responses to global change and restoration, with increased emphasis on relevance for management and conservation of grasslands worldwide (Fig. 2). The theme of global change impacts continued during **LTER V and VI (2002-2014)**, with new emphases on land-use (i.e., altered fire and grazing regimes), land-cover change (i.e., woody encroachment, invasive species), persistent drought, altered biogeochemical cycles, and effects of inter-annual climate variability on grassland restoration. In LTER VI, we also initiated the patch-burn grazing experiment. During **LTER VII (2014-2020)**, we began to explicitly test for resilience and sensitivity to changes in focal drivers using the foundation of decadal-scale measurements in LTERs I-VI to explain ecological dynamics and trajectories of change in tallgrass prairie. Our work during LTER VII provides a foundation for new research focused on the sensitivity and resilience of grasslands to global changes (*see Prior Support*).

Nearly 40 years of KNZ research provides crucial insights into the roles of fire, grazing, climate variability, nutrient supply, and abiotic heterogeneity in the maintenance and dynamics of tallgrass prairie. Decades of manipulating drivers at watershed, plot, and stream-reach scales have created a landscape mosaic of varying ecosystem states (Fig. 4). **LTER VIII (2020-2026)** will capture ongoing dynamic changes through long-term core research and will build on this foundation with new experiments that manipulate drivers in singular or interactive capacities to assess the sensitivity and resilience of ecosystem states (Fig. 4). KNZ research confirms that decadal measurements are required to reveal mechanisms controlling patterns and processes in intact and restored tallgrass prairies (Komatsu *et al.* 2019, Welti *et al.* 2020). Decadal measurements are also needed to reveal legacy effects (*see Box 1*) and feedbacks that maintain altered states when manipulated drivers are ceased or reversed. Collectively, KNZ research will continue to advance ecological theory and improve our mechanistic understanding of ecosystem state changes by manipulating key drivers to alter ecological states and employing new analytical approaches to augment the value of our long-term data sets. Ultimately, the discovery of early indicators of state change and thresholds, knowledge of feedback mechanisms that prevent the reversal of state changes, and legacy effects that promote sensitive or resilient grassland states, will help us to manage, conserve, and restore this imperiled ecosystem and grasslands globally.

III. RESULTS FROM PRIOR SUPPORT

Konza Prairie LTER VII: Long-Term Research on Grassland Dynamics - Assessing Mechanisms of Sensitivity and Resilience to Global Change. Nippert *et al.* 2014-2020. $6,811,998.

During LTER VII, KNZ researchers published 318 refereed papers, 54 student thesis and dissertations, 5 books, 6 book chapters, and 2 other non-refereed scientific products. These include site-focused, multi-site, and synthetic research with contributions to ecology, hydrology, climate science, geology, atmospheric science, and mathematical theory. Over this funding cycle, KNZ scientists leveraged >$17.5M in additional extramural funding to complement and extend the inference of KNZ research. Below, we highlight key results and publications organized by the four thematic areas of the prior proposal. Student contributions are underlined.

IIIA-1. Responses to fire-grazing regimes: Core KNZ research focuses on the role of fire regime and interactions with grazing on long-term dynamics of populations, communities and ecosystems. LTER VII studies extended our understanding of how fire and grazing affect plant and consumer communities and species interactions at multiple scales (Welti & Joern 2018) and the importance of spatial and temporal heterogeneity for species diversity. First, long-term data revealed strong species-specific consumer responses to changing fire, grazing, and climate or habitat disturbance (Jones *et al.* 2017, Welti *et al.* 2017, Williams & Boyle 2018, Bruckerhoff *et al.* 2020). Second, field studies and remote sensing illustrated the impacts of forage quality, habitat heterogeneity, and water availability on bison movement and grazing dynamics (Raynor *et al.* 2016, Ling *et al.* 2019 a, b). Patch mosaics generated by fire and topography play a critical role in maintaining forage availability and nutritional quality for grazers, post-fire vegetative regrowth, and fire-grazer interactions (Raynor *et al.* 2017a, b). Third, our patch-burn grazing experiment illustrated that rotational fire improves habitat for small mammals (Ricketts & Sandercock 2016) and grassland birds (Verheijen *et al.* 2019) in cattle-grazed grasslands.

New research also evaluated the consequences of spatio-temporal fire and grazing heterogeneity on plant, insect and bird communities. Grieger *et al.* (*in review*) found that bison grazing lawns are hotspots of plant diversity, and Shaffer (2019) identified positive feedback mechanisms responsible for grazing lawn persistence. Zahner (2015) illustrated that bison grazing increases plant diversity by releasing non-palatable forbs from aboveground competition. Welti *et al.* (2019a) found that network structural complexity and robustness of insect communities were greater in bison-grazed compared to ungrazed watersheds. Williams (2016) discovered that grassland-dependent birds have high dispersal tendencies in response to high spatio-temporal landscape heterogeneity. For example, grasshopper sparrows (*Ammodramus savanarum*) exhibit high rates (>50%) of dispersal by territorial males in response to fire and grazing combined, rather than their singular effects (Williams & Boyle 2018, 2019).

IIIA-2. Patterns, causes, and consequences of grassland-shrubland/woodland transition: We continued long-term measurements of plant species composition and changes in woody plant cover under different fire and grazing treatments. These data revealed state transitions to shrublands or woodlands following long-term reductions in fire frequency, identification of which was integral to developing and testing theories describing alternative stable states and tipping points in tallgrass prairie (Ratajczak *et al.* 2014a, b, Veach *et al.* 2014). For example, we found that the long time lags preceding woody encroachment present a window of opportunity for early management interventions (Ratajczak *et al.* 2017a). This insight led to a new theoretical framework that describes ecological thresholds in terms of both the magnitude and duration of a change in drivers that must be exceeded before state changes become difficult to reverse (Ratajczak *et al.* 2017b). We identified multiple mechanisms promoting woody species replacing grasses, including reduced competition for water with grasses (O'Keefe & Nippert 2017, Muench *et al.* 2016) and reduced susceptibility to drought under increased [CO$_2$] via lower leaf transpiration (O'Connor 2019). In addition, asexual recruitment remains high in rough-leaf dogwood (*Cornus drummondii*) despite frequent disturbance by fire, grazing and browsing (Wedel 2019).

We addressed mechanisms and consequences of woody encroachment using modeling and novel field experiments. Process-based models explored the relative impacts of climate variability and fire on grass:shrub ratios and carbon assimilation (Brunsell *et al.* 2017). Spatially explicit models illustrated the effects of fire frequency on transient dynamics and spatial heterogeneity of plant growth rates (Ratajczak *et al.* 2017a). Simulation of greater browsing pressure—as might have occurred before elk extirpation—suggested a strong potential for synergistic interactions between browsing and fire on shrub mortality (O’Connor *et al.* 2020). We initiated the Shrub Rainfall Manipulation Plots experiment (ShRaMPs) in 2017 to test drought impacts woody on encroachment. Preliminary results suggest drought effects on shrub physiology, morphology, and demography are as pronounced as fire effects. Finally, a riparian woody removal experiment, begun in 2010, examined the impacts of woody plant expansion on ecohydrology, stream biogeochemistry, and geomorphology. Stream flow was minimally influenced by the removal of woody plants along the stream corridor, but nitrogen (N) and phosphorus (P) export increased for 3 years before returning to control levels (Larson *et al.* 2019). Woody removal also stimulated denitrification in riparian and benthic zones (Reisinger *et al.* 2013), and microbial community structure (Veach *et al.* 2015), showing that woody encroachment has consequences at the ecosystem level.

III-B. Climate variability and climate change: Detailed climate records and ecological measurements for KNZ now span 40 years, providing context for understanding how tallgrass prairie responds to changes in climate means and extremes (Smith *et al.* 2015, Knapp *et al.* 2017b). KNZ has a long history of long-term climate manipulation experiments (RaMPs 1998-2016, Irrigation Transect Study 1992–present, Climate Extremes Experiment (CEE) 2010-present). These and a suite of shorter-term experiments provided opportunities to combine experimental and observational data to determine how grassland sensitivity to climate is altered by long-term changes in hydroclimatic conditions (Ponce-Campos *et al.* 2013), ecosystem eutrophication (Flores-Moreno *et al.* 2016), and to identify mechanisms underlying sensitivity and resilience to climate changes. The CEE has assessed the resilience of grassland communities and ecosystem processes to repeated extreme droughts. Aboveground productivity was highly sensitive, yet highly resilient after 2-year manipulations of drought and air temperature (Hoover *et al.* 2014, 2017). However, long-term resistance declined following repeated extreme 2-yr droughts. Grass bud and shoot densities appear resistant to drought (VanderWeide & Hartnett 2015), suggesting that grass rhizomes and buds can buffer responses to drought and help explain this ecosystem’s resilience (Hoover *et al.* 2014). Analysis of long-term data from the Irrigation Transect study showed that despite drastic alteration in resource availability, shifts in plant communities maintain ANPP (Collins *et al.* 2012, Wilcox *et al.* 2016a), and critical ecosystem services (i.e., carbon sequestration) (Wilcox *et al.* 2016b).

During LTER VII, we modified the Irrigation Transect experiment to examine how legacies of multi-decade climate manipulations affect responses to novel climates or climate extremes. We imposed a 66% reduction in growing season rainfall in a subset of plots with a history of either ambient rainfall or addition of supplemental rainfall to eliminate water limitation. To date, the legacy effects of long-term irrigation include elevated ANPP and soil respiration, but increased sensitivity of microbial biomass to drought

(Broderick *et al.* unpublished). Similarly, we modified the Rainfall Manipulation Plots (RaMPs) experiment, which historically altered within growing-season precipitation variability (but not amount), by imposing an extreme 2-year drought (2014-2015), followed by a recovery year (2016). Plant community composition and ANPP responses to extreme drought were unaffected by more than a decade of increased rainfall variability. In contrast, greater variability increased sensitivity of BNPP, and soil CO_2 flux to drought (Slette *et al.* unpublished). Further, microbial respiration decreased in soils with greater drought history, corresponding with lower mortality of microbial populations following soil drying and rewetting (Zeglin *et al.* 2013, Veach & Zeglin 2019). These results suggest that belowground legacies of past climate conditions influence system resilience to future climate changes (Slette *et al.* unpublished).

The long-term studies at KNZ provide unique opportunities to assess the impacts of extreme events, such as heatwaves, droughts and floods. Ratajczak *et al.* (2019) showed that the combined effect of heatwave and wildfire altered the plant community more than either did independently. During LTER VII, two anomalous climate years (drought in 2018 and floods in 2019) occurred, and several studies suggest that they affected consumer responses. Hopper *et al.* (2020) used a series of physiological performance experiments to predict traits of fish species that could survive in isolated pools with harsh abiotic conditions during the 2018 drought. Hedden and Gido (2020) estimated that >40% of fishes in isolated downstream habitats returned to the middle reaches of Kings Creek in 2019 after flow was restored, suggesting fish communities may be quite resilient to drought.

III-C. Altered Biogeochemical Cycles: Characterizing feedbacks between altered biogeochemical cycles and grassland state changes is integral to KNZ research, because nutrient availability alters aboveground community states and stability (Avolio *et al.* 2014, Koerner *et al.* 2016). Moreover, the consequences of state change for nutrient cycling and export can be substantial (Larson *et al.* 2019).

KNZ maintains four long-term nutrient manipulation experiments. Recent results from the Belowground Plots experiment (1986-current) showed that soil bacterial communities were more sensitive to fertilizer addition in unburned prairie, suggesting a combined effect of multiple drivers of N availability (Carson & Zeglin 2018). In contrast, fungal responses appeared more related to plant community turnover than N availability per se (Carson *et al.* 2019). In 2017, we ceased N additions to evaluate legacies of nutrient enrichment, and found that N-cycling rates and microbial populations were differentially resilient; microbial-mediated N loss in the unburned treatment might control recovery of the system to a low-N state, while fire-mediated N losses may dominate in burned prairie (Nieland *et al.* in review). The P-Plots Experiment (2001-current) revealed that combined N and P enrichment shifted the plant community from a C_4- to C_3-dominated state, accompanied by increased year-to-year variation in productivity (Avolio *et al.* 2014) and reduced grassland state stability over time (Koerner *et al.* 2016). KNZ was an inaugural Nutrient Network (NutNet) site in 2008, contributing data to regional syntheses assessing the effect on nutrient additions on NPP, invertebrate communities, and soil organic matter decomposition (La Pierre *et al.* 2016, La Pierre & Smith 2016, Riggs & Hobbie 2016). KNZ NutNet data also were included in several global studies examining productivity-diversity relationships (Adler *et al.* 2011, Grace *et al.* 2016), climate and anthropogenic impacts on species invasions (Flores-Moreno *et al.* 2016), and effects of single- and multiple-resource limitation on plant species coexistence and function (Borer *et al.* 2014, Fay *et al.* 2015, Stevens *et al.* 2015, Harpole *et al.* 2016, Hodapp *et al.* 2018, Hautier *et al.* 2018), arthropod communities (Lind *et al.* 2017) and microbial diversity (Leff *et al.* 2015, Prober *et al.* 2015). Finally, the Chronic Addition of Nitrogen Gradient Experiment (ChANGE) adds eight levels of N (0-30 g m^{-2}) to annually burned grassland plots to understand how varying levels of N enrichment affect community composition, ANPP and insect herbivory, and to examine potential thresholds of N effects on community responses. Results indicate additional increases in ANPP above 5 g N m^{-2} enrichment in years with above average rainfall, with no N effect on plant communities to date. Data from the KNZ ChANGE experiment also illustrates that insect herbivores can be subject to N-P co-limitation (Rode *et al.* 2017).

We also conduct long-term measurements of precipitation (wetfall and dryfall), groundwater, and stream water chemistry. Hydrologic research at KNZ characterizes weathering and changes in belowground flow paths to the broader karst landscape. Groundwater chemistry data revealed a ~40% increase in groundwater pCO_2 over the past 3 decades (Macpherson *et al.* 2008, Macpherson & Sullivan 2019, Sullivan *et al.* 2019). Groundwater levels (1990-present) and stream discharge (1986-present) have decreased, although precipitation over this period has not. Changes in groundwater flow paths (Brookfield *et al.* 2017, Vero *et al.* 2018) may help explain variability in stream discharge; more specifically, Costigan *et al.* (2015) suggested that water accumulation and storage in shallow limestone and alluvium aquifers creates threshold dynamics in the relationship between precipitation and stream flow. Long-term records of dissolved organic carbon (DOC) in streams demonstrate the influence of this hydrologic variability on DOC flux from the watersheds, and show low concentrations relative to other grasslands globally (Rüegg *et al.* 2015). Analyses of stream metabolism showed high heterogeneity of ecosystem processes over reach scales (Siders *et al.* 2017). We continued N cycling studies in Kings Creek (Resinger *et al.* 2013, Trentman *et al.* 2015) and used these results to illustrate similarities with other grassland streams (Norman *et al.* 2017, Higgs 2018, Tank *et al.* 2018).

III-D. Restoration Ecology: Restoration studies at KNZ include community and ecosystem dynamics in terrestrial and aquatic systems. Experimental prairie restorations aim to reveal the relative roles of deterministic and stochastic processes on restoring plant diversity and ecosystem functions during transitions from cropland to a prairie state (Fig. 4). The first restoration experiment (1998-present) is a long-term test of the environmental heterogeneity hypothesis, demonstrating that variability in soil resources increases plant diversity when propagules of new species are supplied (Baer *et al.* 2016, 2020). The sequential prairie restoration experiment (2010-present) evaluates the role of inter-annual variability in climate on plant community development. Results thus far establish that inter-annual precipitation variability leads to structurally and functionally different plant communities after the first three years of restoration (Manning 2018, Manning & Baer 2018), but community structure and ecosystem function are expected to converge over time (Scott & Baer 2018, 2019). Multiple restoration experiments co-located at KNZ provide a 35-year restoration chronosequence used to quantify decadal-scale rates of ecosystem recovery. Recent studies across this chronosequence showed that available nutrient pools decline as labile C pools increase (Rosenzweig *et al.* 2016), that nitrous oxide production also declines over time as inorganic N becomes less available (Scott *et al.* 2019), and that sequestered C is affected more by the recovery of microbial communities than by soil structure (Scott *et al.* 2017).

III-E. 10 Most Significant Publications during LTER VII (2014-2020) *graduate student author*

1. Baer SG, Blair JM, Collins SL. 2016 Environmental heterogeneity has a weak effect on diversity during community assembly in tallgrass prairie. *Ecological Monographs* 86:94 -106
2. Carson CM, Zeglin LH. 2018 Long-term fire management history affects N-fertilization sensitivity, but not seasonality, of grassland soil microbial communities. *Soil Biology & Biochemistry* 121:231-239
3. Dodds, WK, Gido, K, Whiles M, Daniels M, Grudzinski B. 2015 The Stream Biome Gradient Concept: Factors controlling lotic systems across broad biogeographic scales. *Freshwater Science* 34:1-19
4. Hoover DL, Knapp AK, Smith MD. 2014 Resistance and resilience of a grassland ecosystem to climate extremes. *Ecology* 95:2646 -2656
5. Knapp AK, Carroll CJ, Griffin-Nolan RJ, Slette IJ, Chaves FA, *et al.* 2018 A reality check for climate change experiments: Do they reflect the real world? *Ecology* 99:2145-2151
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III-F. Summary of the table of datasets included as a supplementary document – The KNZ website provides access to 135 projects, consisting of 350 datasets available online (152 are GIS data). These datasets are searchable by LTER core areas and we update them in the LTER Environmental Data Initiative (EDI) data portal and DataOne. During LTER VII, we improved the search capabilities of our structured metadata, which are fully compatible with the LTER Network Information System. During the 2014-2020 LTER VII funding cycle, 385 KNZ LTER-supported/related publications, thesis and dissertations were added (cumulative total of 1889 publications since LTER I).

III-G. Supplemental Funding – NSF provided $50K in supplemental equipment funding in 2015. This was used to purchase automated soil respiration sensors, two replacement neutron soil moisture probes, and groundwater sampling equipment. Soil respiration sensors were paired with two eddy flux towers (Ameriflux sites US-KON and US-KFB) to enhance CO_2 flux partitioning (Brunsell *et al.* 2017). Long-term soil moisture data comprise a core KNZ dataset (ASM01) collected from 1983 to present. Recent groundwater research describing chemical weathering benefitted from the additional equipment provided by this supplement (Macpherson & Sullivan 2019, Sullivan *et al.* 2019).

III-H. Broader Impacts – *Education:* During LTER VII, 54 graduate students from 9 institutions completed theses and dissertations. Over 105 undergraduates, including 33 REU students, participated in KNZ research. An additional 200-300 undergraduates *per year* used KPBS for field trips, course activities, and research tours. The Konza Schoolyard LTER (SLTER) program engaged 800-1000 local schoolchildren *per year* in site-based science at KPBS and provided experience in the use and sharing of data in collaborative learning and research activities. The broader Konza Environmental Education Program (KEEP) provided informative field tours and educational experiences for an additional 2500-3000 schoolchildren annually. *Engagement with Art:* KPBS hosts local and national artists, writers, and photographers to broaden public awareness and appreciation of grassland ecosystems and of science more generally. One local example is the Prairie Studies Initiative, a collaboration of K-State faculty, students, and the public to explore the cultural and ecological dimensions of prairies. *Conservation:* KNZ scientists provided numerous research tours to the public, land managers and conservationists, and >50 grassland-related professional groups totaling >3,000 individuals visited KPBS for information and training. We work closely with *The Nature Conservancy* and K-State Extension to translate research results into management best-practices and conservation recommendations.

III-I. Synthesis, cross-site, and LTER network level activities – KNZ investigators led or participated in numerous cross-site syntheses to develop and test ecological concepts. Noteworthy examples included: temperature sensitivity of litter decomposition (Follstad-Shah *et al.* 2017), activation energies of stream metabolic rates (Song *et al.* 2018), drivers of ecosystem regime shifts (Ratajczak *et al.* 2017b), grassland responses to climate change (Hufkens *et al.* 2016, Ladwig *et al.* 2016), community responses to multiple global change drivers (Komatsu *et al.* 2019), ecosystem responses to fire and grazing (Smith *et al.* 2016), spatial dynamics and ecosystem stability (Wilcox *et al.* 2017b), a global assessment of biodiversity responses to large grazers (Koerner *et al.* 2018), and a synthesis of multi-trophic responses to nutrient enrichment in streams (Ardón *et al.* in review). KNZ scientists played lead roles in the Nutrient Network and the NSF Drought-Net Research Coordination Network, the USDA funded Grazing Exclosure Consortium (GEx), as well as SCALER (Scale, Consumers, and Lotic Ecosystem Rates). KNZ led and participated in many Network-level activities, including a synthesis working group *(Integrating Plant Community and Ecosystem Responses to Chronic Global Change Drivers: Toward an Explanation of Patterns and Improved Global Predictions* - led by Komatsu, Avolio, and Wilcox). In addition, KPBS hosted the 2014 Science Council, Nippert serves on the Executive Board (2019-present), and Knapp chairs the LTER Publications Committee.

IV. RESPONSE TO THE MID-TERM SITE REVIEW

The KNZ mid-term site review occurred in Sept 2017. The review summary provided by Dr. Doug Levey was very supportive of the scope and focus of current KNZ science. The summary highlighted the strength of our current research focus and conceptual model stating: "*The Program is in complete agreement with panelists that KNZ is maintaining its considerable momentum in cutting-edge research on mechanisms of sensitivity and resilience to global change in grassland ecosystems...There was strong consensus among panelists that the third major phase of KNZ LTER research is exciting and based on a fresh conceptual framework… The Program agrees with panelists that the quality and quantity of research underway at KNZ is nothing short of outstanding."* Based on feedback from this review and the initial promising results from a focus on grassland resilience, this renewal proposal (VIII) builds upon our conceptual framework and the well-received LTER VII theme. The team provided several constructive recommendations for improvement. We were encouraged to modify or halt long-term treatments in selected experiments to facilitate new investigations of resilience and sensitivity. In LTER VIII we will continue to assess recovery after cessation of N fertilization in the Belowground Plot Experiment and will increase fire frequencies in historically low frequency treatments with high woody encroachment. A second suggestion was to increase use of quantitative models across spatial scales, and modelling that integrates across the five core areas of LTER. Here, we propose new projects using quantitative spatial tools, integral projection models for improved understanding of fundamental population ecology, as well as a Bayesian data integration framework for predictive inference of spatial and temporal variation in populations, communities and ecosystems (detailed in *VI-E*: *Synthesis*). A third suggestion was to increase focus on the mechanistic feedbacks between plants and herbivores. Several new projects, including *ConSME* (#6 in project descriptions), *GRaMPs* (#14), and *Fire reversal in bison watersheds* (#19) are new projects to assess ecological responses to grassland herbivory. No major concerns were noted for the other project criteria (IM, Network participation, Education/ Outreach, & Site Management).

V. FRAMEWORK FOR LTER VIII

The KNZ long-term experimental template provides unparalleled opportunities for advancing ecological theory and addressing timely questions regarding grassland responses to multiple, interacting global changes. Our ***conceptual framework*** (Fig. 2) integrates the increasing complexity of LTER objectives over time and recognizes that the key drivers of pattern and process in grasslands are influenced by human activities at local (e.g., land use and management), regional (e.g., nutrient inputs) and global (e.g., climate change) scales. LTER VII initiated a new phase of KNZ research, focusing on the mechanisms that underlie the sensitivity and resilience of ecosystem states in mesic grasslands (Smith *et al.* 2009). LTER VIII will advance our investigation of grassland resilience using legacies of landscape fire and grazing experiments, experimental manipulations of global change drivers, and human intervention to restore non-grassland states to grassland. Specifically, we will: 1) reverse previous manipulations of external drivers to identify feedbacks preventing or promoting resilience, 2) alter drivers continuously (~ press) as well as episodically (~ pulse) to assess sensitivity and detect points when subtle environmental changes lead to large changes in ecosystem state (~ thresholds), and 3) use factorial combinations of multiple drivers to determine if synergistic interactions increase sensitivity or decrease resilience. Using this framework, we are poised to discover novel ecological responses, further our understanding of grassland resilience, and contribute to grassland conservation and restoration in the face of ongoing landscape and associated global changes.

Variation in fire frequency, grazing, climate variability, and nutrient availability can produce different grassland ecosystem states (Fig. 4; Collins & Calabrese 2012, Ratajczak *et al.* 2014a, b, Veach *et al.* 2014, Carson & Zeglin 2018, Avolio *et al.* 2018, Smith *et al.* 2020). State changes at KNZ follow the theory predicted by various dynamical-system models (Scheffer *et al.* 2001, Ratajczak *et al*. 2018) and in response to global change drivers (Smith *et al.* 2009). Changes among states can be 1) *gradual and reversible*, 2) exhibit abrupt thresholds that *are reversible* (regime shift), or 3) cross thresholds that *are* *difficult to reverse* (regime shift with hysteresis), with the latter resulting in a transition to an alternate stable state due to stabilizing feedbacks (Scheffer *et al.* 2001, Bestelmeyer *et al.* 2011, van Nes *et al.* 2016). In systems with hysteresis, crossing a threshold often leads to a transition to an often undesirable, alternate state (Scheffer *et al*. 2001, Petraitus 2014).

The hierarchical-response framework (HRF; Smith *et al.* 2009) is a conceptual model used to understand and predict underlying state change under press drivers associated with global change. This model predicts that continued accumulation of resources leads to rapid physiological or metabolic responses by individuals. For example, more water or nutrients results in faster individual growth of dominant plant species (Avolio *et al.* 2014). However, as resource accumulation continues, physiological limits of some species are exceeded, triggering species reordering and shifts in dominance (Isbell *et al.* 2015, Koerner *et al.* 2016, Smith *et al.* 2020). After that, competitive exclusion and immigration leads to species losses or gains, resulting in further changes in community composition. In the long term, community re-ordering results in greater ecosystem-level responses than the early, individual species-level response alone, since different species now dominate ecosystem processes. The time for these mechanisms to manifest can vary. For example, plant composition was stable through 19 years of irrigation in shallow soil uplands, but significant shifts occurred after three years of irrigation in lowlands (Czóbel & Orsolya 2009, Collins *et al.* 2012). Different biotic or abiotic factors may stabilize or alter state changes over time, such as nutrient co-limitation, availability of augmented resources, different physiological rates and constraints of existing species, positive or negative interactions among, or dispersal capabilities of, existing and novel species. Identifying these mechanisms is key to understanding thresholds and feedbacks that underlie the sensitivity and resilience of any ecosystem state, including tallgrass prairie.

Building upon state-change models and the HRF, our overarching ***theoretical model*** (Fig. 5) predicts varying sensitivity and resilience among grassland states in response to manipulated drivers (model developed from Scheffer *et al.* 2001, 2009, Folke *et al.* in 2004, Bestelmeyer *et al.* 2011). We propose

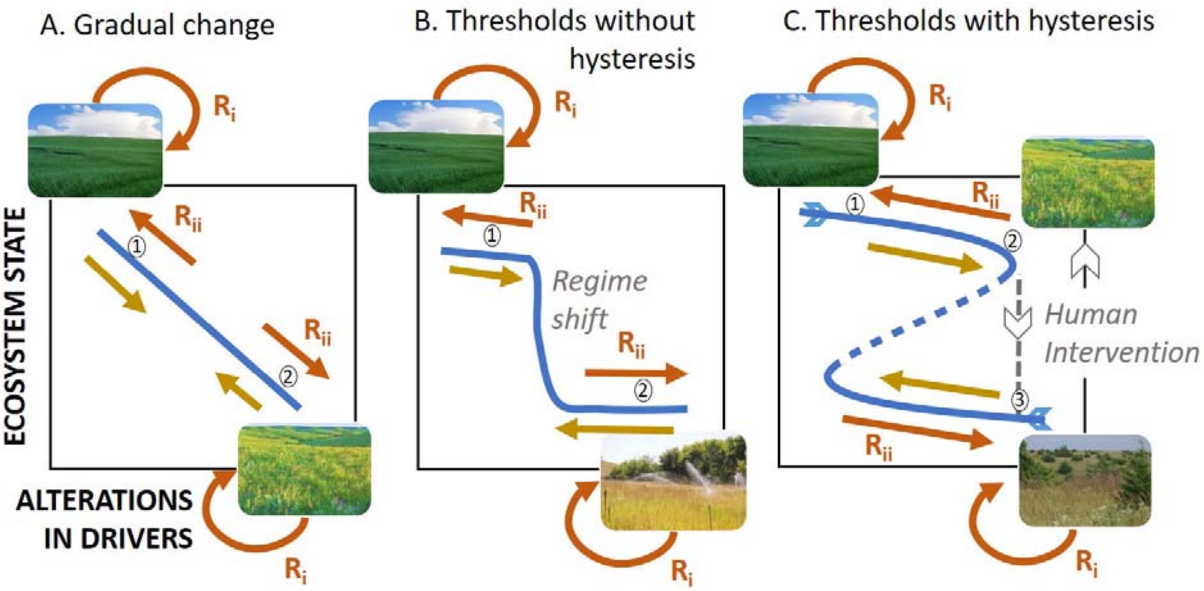

Fig. 5: Theoretical model illustrating shifts in grassland ecosystem state (y-axis) to alteration in drivers (x-axis) when change is: A. Gradual, B. Thresholds without hysteresis, and C. Thresholds with hysteresis. Within a particular state, resilience (orange arrows) reinforces dynamics, while sensitivity (gold arrows) dictates the likelihood of a transition from one state to another in response to altered grassland drivers. We are aware that <u>*Resilience*</u> has been defined many ways; here R_i indicates <u>resistance</u> to change, while R_{ii} indicates <u>recovery</u> to the original conditions (defined in Box 1). Blue lines indicate trajectories of change. Numbered balls indicate points in time. Pictorial examples of states correspond with Fig. 4.

that ecosystem resilience in tallgrass prairie varies with the type, frequency, and number of manipulated drivers and that state change proceeds along linear or nonlinear trajectories, with the latter potentially exhibiting thresholds and hysteresis that depend on mechanisms of population, community, or ecosystem change. For example, gradual linear changes occur with long-term bison grazing such that floristic richness increases and grass dominance decreases over time (Fig. 5a; Koerner *et al.* 2014). Alternatively, long-term nutrient and water addition leads to nonlinear responses of plant community composition (as predicted by the HRF; Smith *et al.* 2009); shifts in state appear to be maintained by weak feedbacks (Koerner *et al.* 2016, Wilcox *et al.* 2016a, Avolio *et al.* 2018; Baer *et al.* 2019) (Fig. 5b). Finally, a reduction in fire frequency results in a grass-to-shrubland or woodland transition (Briggs *et al.* 2005, Veach *et al.* 2014) that exhibits thresholds (Ratajczak *et al.* 2014a) and hysteresis (Ratajczak *et al.* 2017a, b) (Fig. 5c). Following the transition to an alternate shrubland state, recovery of the grassland state likely requires human intervention or a novel combination of multiple grassland drivers (i.e., extreme drought). When grassland is reconstructed from former cropland agriculture, we predict that climate-driven variation in initial community structure determines the trajectory of community recovery and future resilience. For the new and continuing research projects in LTER VIII, this theoretical framework, along with the HRF, guides our assessment of the resilience and sensitivity of ecosystem states, trajectories of change (when possible), identification of potential mechanisms determining different trajectories of change, and determination of ecologically sound recommendations for restoration.

VI. New and Continuing Research for LTER VIII

Research conducted by KNZ LTER scientists is well-known for demonstrating how alterations in both natural (historical) and forecast global change drivers can result in a wide variety of distinct grassland states (Fig. 4, Smith *et al.* 2020). The need to understand the relationships between these drivers and their resulting ecological states, and the mechanisms that generate and reinforce these states, form the organizing basis for both new and continuing research proposed in KNZ LTER VIII. We organize our proposed research around four thematic areas: 1) **Historical Drivers** that maintain the tallgrass prairie state. Projects described in this section include some of the longest-running studies at KNZ, with data from these constituting many long-term core datasets. Both landscape-scale experiments (fire and grazing) and long-term, plot-level manipulations of drivers (fire, grazing, climate) are included. Here, experimental treatments tend to be within the historical range of variability for the ecosystem (Morgan *et al.* 1994). 2) **Experimental Manipulations of Global Change Drivers** will be imposed at more extreme levels than historically experienced, and in new combinations to reveal interactions among drivers. This includes many plot-level experiments designed to probe system resilience and reveal grassland sensitivity to interacting drivers (e.g., rainfall reduction with grazing), and/or extreme drivers (e.g., persistent, repeated drought). 3) **Cessation / Reversal of Drivers** will assess ecological legacies and hysteresis. Reversal of drivers in long-term experiments at KNZ (e.g., switching between long-term fire suppression and annual burning or halting nutrient addition to long-term fertilized plots) provides rare opportunities to understand resilience and identify instances of hysteresis in terrestrial ecosystems. 4) Direct **Human Intervention** will assess our ability to restore non-grassland states to grassland and reconnect isolated populations. We will examine the role of inter-annual variability in climate on recovery of grassland states from agricultural states through propagule additions over time, manipulate the presence of species (e.g., woody plant removal) to convert shrub/woodland to prairie, and transfer individuals from disconnected populations to increase resilience.

Within each of these themes, we highlight *Continuing* and *New* research projects that explicitly address the five LTER core areas, with broad emphases on producers, consumers, biogeochemistry and hydrology. The number of each research project corresponds with the research locations shown in Fig. 3.

VI -A: Historical Drivers of tallgrass prairie – Tallgrass prairie ecosystems are dynamic, shifting in composition and diversity when exposed to variation in the historical drivers of climate, fire frequency, and grazing (Collins *et al.* 2012, Zahner 2015). Primary productivity of tallgrass prairie is subject to frequent water (Knapp *et al.* 2001) and N limitation (Blair 1997) whose magnitude varies with fire, grazing, and topography (Nippert *et al.* 2011, O'Keefe & Nippert 2017). Yet, this ecosystem has a high capacity for carbon storage and nutrient retention in soils, with low stream nutrient export (Dodds *et al.* 2000, Dell & Rice 2005). In addition to the landscape-scale fire and grazing studies, KNZ uses plot-level experiments to investigate how changes in nutrient availability and hydrology influence ecosystem dynamics (Avolio *et al.* 2014, Koerner *et al.* 2016, Wilcox *et al.* 2016a). Much of what we know about tallgrass prairie sensitivity and resilience comes from this integrative plot-to-landscape experimental design.

CORE LONG-TERM STUDIES AND CONTINUING EXPERIMENTS:

KNZ fire and grazing studies and datasets address all five LTER core areas (primary productivity, nutrient cycling, organic matter, population and community dynamics, and disturbance). Frequent fire maintains tallgrass prairie in a C_4 grass-dominated state (Knapp & Seastedt 1986). Fire affects litter accumulation, which influences light and soil nutrients for emerging plants. Frequent spring fires remove surface litter, alleviating light limitation early in the growing season and increasing N limitation due to volatilization and immobilization in high C:N grass litter. C_4 grasses respond with increased aboveground productivity (ANPP), while C_3 plants (including woody species), exotic species, and overall floristic diversity declines (Collins *et al.* 1998, Smith *et al.* 1999). In contrast, fire suppression increases surface litter, decreases C_4 grass dominance, and promotes the conversion of grassland to shrub- or woodland (Fig. 6) (Briggs *et al.* 2005, Ratajczak *et al.* 2014a, b). Extended accumulation of plant litter from infrequent fire leads to greater soil N mineralization (Turner *et al.* 1997) and lower N retention in soil microbes and organic matter (Dell *et al.* 2005). Changes in vegetation structure, composition, and tissue quality under contrasting fire regimes affect consumers and soil microbes (Carson *et al.* 2019). Grazers also play a crucial role in grasslands by preferentially using recently burned sites and altering soil nutrient availability, plant communities, and habitat structure (Knapp *et al.* 1999, Raynor *et al.* 2015, Koerner *et al.* 2014, Welti *et al.* 2019a, b). Large grazers preferentially consume the dominant grasses (Smith *et al.* 2016, Koerner *et al.* 2018), promoting plant diversity, increasing heterogeneity at multiple scales, and altering the abundance and diversity of

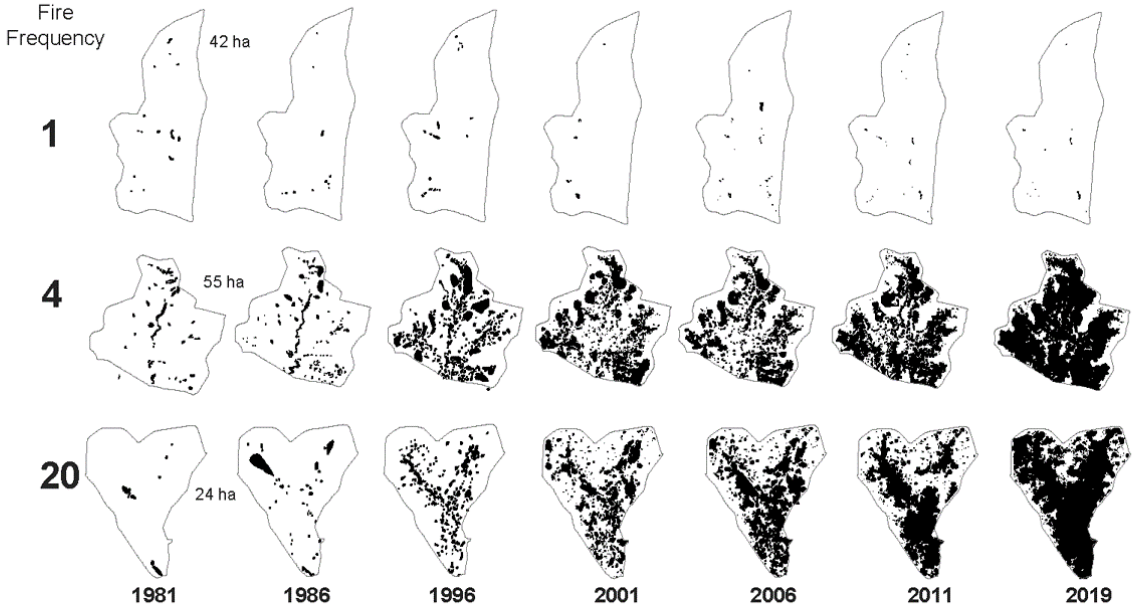

Fig. 6: Changes in cover of major shrub species under contrasting fire regimes (1981-2019). Black color indicates shrub incursion. In areas burned annually (top row), woody encroachment is negligible. Under a 4-yr fire frequency (middle row) and a 20-yr frequency (bottom row), transition to new shrub- and/or tree-dominated ecosystem states have occurred. From KNZ dataset GIS660.

other consumers (Ricketts & Sandercock 2016). Grazers convert plant-N to more soil-available forms (Johnson & Matchett 2001), and thus can increase N cycling even under frequent fire.

1. Long-term changes in plant composition – The longest running KNZ plant community dataset (PVC02) details changes in percent cover of all plant species in watersheds subjected to three fire frequencies (1-, 4-, & 20-yr), with and without bison. Long-term datasets also exist for many other watershed-level treatments, such as different seasons of fire and the fire reversals (reversal of 1- vs. 20-yr fire frequency treatments). These data are invaluable for testing hypotheses related to patch dynamics, invasibility, top-down control, meta-communities, transient dynamics, disturbance responses, and hysteresis/alternative states (Smith *et al.* 1999, 2020, Collins & Calabrese 2012, Ratajczak *et al.* 2014a).

2. Long-term changes in consumer communities – KNZ consumer studies have focused on bison given their historical importance in tallgrass prairie (Knapp *et al.* 1999), as well as small mammal populations that track changes in vegetation and climate (McMillan & Kaufman 1994, Reed *et al.* 2004). Invertebrates, fish and birds are also important consumers that vary in trophic level, size, metabolic capabilities, habitat, and vagility. We will continue long-term measurements of these groups to assess responses to spatial and temporal heterogeneity associated with watershed treatments and climatic variability. Recent synthesis work elucidated spatial and temporal changes across multiple consumer groups. Directional changes in bird, small mammal and grasshopper communities over time on KPBS were associated with reordering of species rather than changes in species richness (Jones *et al.* 2017), and long-term KNZ data to show that small mammals and grasshoppers responded more strongly to climate variability than plant or bird communities (Bruckerhoff *et al.* 2020). LTER VIII will build on this prior work to develop spatio-temporal models that forecast effects of climate and fire/grazing regimes on multiple consumer guilds (described in *Section VII. Synthesis*).

3. Long-term stream nutrients – The Kings Creek watershed serves as the only USGS long-term reference watershed completely surrounded by native tallgrass prairie. KNZ stream and groundwater sampling provides data with which to assess linkages between terrestrial ecosystem states and downstream ecosystems. We have identified mechanisms controlling transformations of N, P, sediments, and DOC (Kemp & Dodds 2002, O'Brien & Dodds 2008, Banner *et al.* 2009, Ding *et al.* 2013, Larson *et al.* 2013, Rüegg *et al.* 2015) using these data on stream nutrients. We observed recent large decreases in nitrate in wells near the lower stream reaches, where we have restored near-stream cropland to grassland (Fig. 7). In addition to continuing long-term sampling, we have begun measuring rates of N cycling (nitrification, denitrification, mineralization) in coupled riparian soil and in-stream reaches. In LTER VIII, **we hypothesize that changes in riparian N cycling and hydrology will alter spatial and temporal dynamics of in-stream N processing as a result of management and land cover change.**

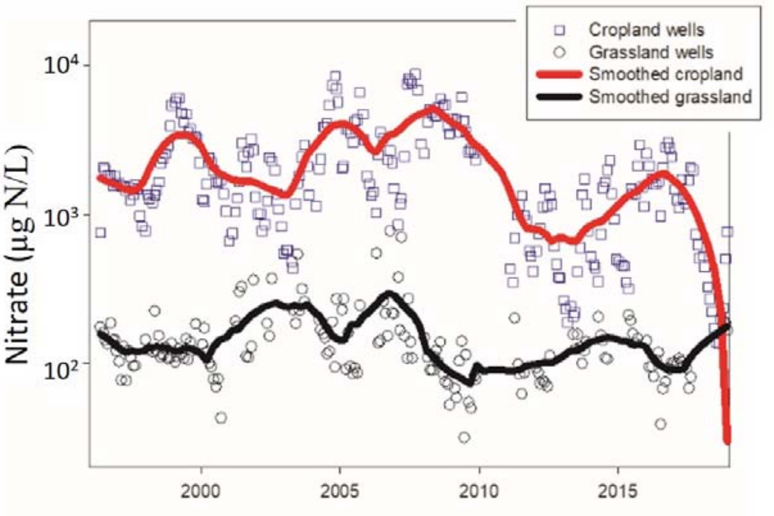

Fig. 7: Long-term nitrate concentrations measured from wells in grassland and adjacent to cropland agriculture undergoing restoration (since 1997). From KNZ dataset AGW02.

4. Patch-burn grazing (PBG) experiment – We will continue a long-term patch-burn grazing experiment (2010-present) to determine how the spatiotemporal dynamics of fire-grazing interactions generate heterogeneity of plants and consumers in a managed grassland system. This experiment includes two large replicate cattle grazing units, each consisting of three watersheds (Fig. 3). In each unit, all three watersheds (patches) are open and equally accessible to cattle. Watersheds are burned on a staggered 3-yr rotation such that in any given year, patches have 0, 1, 2 years since fire. Two additional paired watersheds serve as 'controls' that are burned annually and grazed by cattle at the same density as the patch-burn units. Like bison, cattle preferentially use recently burned areas (Towne *et al.* 2005), resulting in a shifting mosaic of grazing pressure. With the PBG experiment, **we hypothesize that increased spatial heterogeneity from patch-burn grazing will increase plant and consumer diversity and decrease temporal heterogeneity of population and community responses to climate variability.** To date, habitat heterogeneity has increased across the PBG units, with variable responses in plant, grasshopper and bird abundances (Fig. 8). We will start the third cycle of rotational burning during KNZ VIII, allowing us to assess how grazing-fire induced heterogeneity interacts with climate variability over time. In addition to continuing long-term data collection (plant, grasshopper, small mammal, bird composition and abundance, and grazer productivity), we add new data on water quality (nutrients and sediments), stream geomorphology, soil nutrient availability and microbial communities. This experiment reveals the consequences of PBG for multiple ecosystem functions and biodiversity, as compared to the traditional management practice of annual burning and continuous cattle grazing.

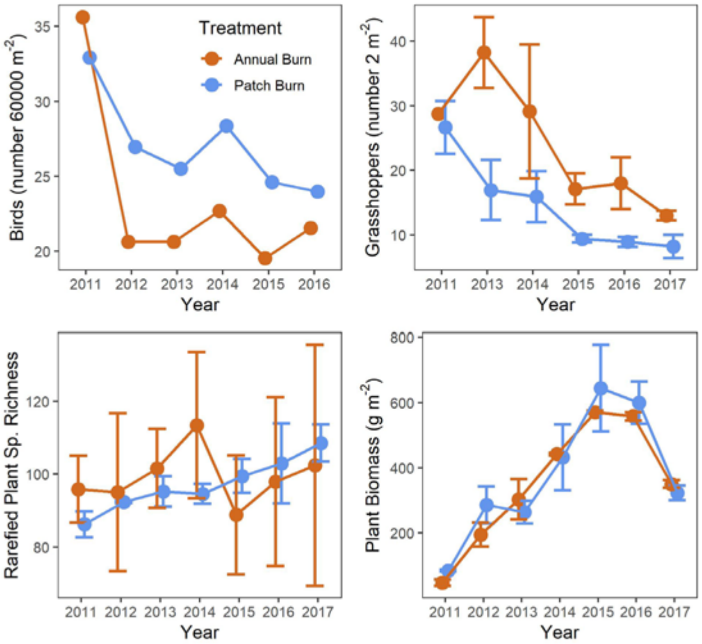

Fig. 8: Long-term PBG data (2011-2017) from KNZ datasets PBG051, -081, -011, & -032. Control watersheds (orange) are annually burned and grazed, while patch-burn units (blue) include three watersheds grazed and burned on a 3-yr rotation. Count data indicate average number of individuals observed. Plant species richness indicates rarified number of species (landscape scale) or average aboveground biomass in a plot (patch scale).

NEW LTER VIII EXPERIMENTS:

5. "Ghost Fire" Experiment – Fire removes litter, decreases N availability, increases light availability, and reduces soil moisture (Seastedt & Knapp 1993). Changes in light and N availability with frequent fire promotes the dominance and productivity of C_4 grasses and decreases plant diversity. While we understand how plant communities and ANPP are affected by N and light availability (Blair 1997, Collins *et al.* 1998), less is known about belowground NPP, and microbial and insect community responses. Ghost Fire is the first experiment that directly and independently tests the relative importance of both mechanisms (changes in litter and N availability) underlying the effects of fire. **We hypothesize that litter and N manipulations will differentially affect above- and below-ground communities and processes, but neither manipulation individually will explain observed responses to fire. We also hypothesize that the importance of each mechanism will vary over time with inter-annual climate variability**. To evaluate these hypotheses, we have factorially manipulated litter presence and N availability (via sugar/urea additions) in 6 m^2 plots within both annually burned and unburned watersheds since 2015. Annually, we measure plant species composition, aboveground NPP, and light availability. With LTER VIII, we will add new measures of soil N, microbial composition and activity, root biomass and productivity, mycorrhizal colonization rates, and insect composition and abundance. These data will enable us to evaluate the strength of above- and below-ground responses concurrently, as well as effects in dry vs. wet years.

Fig. 9: Bison grazing around a ConSME bison exclosure. Each plot is 25 m^{-2} with a 4 m^{-2} core measurement area, allowing space for the experiment to be used as a platform for future data collection and additional experimental manipulations.

6. Consumer Size Manipulation Experiment (ConSME) – The top-down effects of herbivores and their interactions with bottom-up drivers (fire, precipitation, and nutrient availability) on NPP and plant community composition vary across grassland ecosystems (Olff & Ritchie 1998, Maron & Crone 2006, Hillebrand *et al.* 2007, Gruner *et al.* 2008), likely due to the wide range of herbivore types within and across grasslands (Borer *et al.* 2005, Bakker *et al.* 2006). We propose to determine how different size classes of consumers (bison, small mammals, invertebrates) at KNZ affect plant community composition and ecosystem function, as well as the mechanisms underlying these effects. **We hypothesize that size-specific consumer effects on the plant community will reflect herbivore dietary preferences and biomass removal rates.** Established in 2019 (after 1-yr of pre-treatment data), ConSME includes bison and invertebrate removal treatments crossed in a fully factorial design, with small mammal removals nested within the bison removals, for a total of six treatment combinations (Fig. 9). The six treatment combinations are applied to 9 experimental blocks in both an annually burned (N1A) and 4-yr burn (N4B) watershed (Fig. 3). Bison are excluded with fencing; small vertebrate herbivores are excluded with fine mesh fencing buried to 10 cm and topped with smooth metal flashing; insect 'removals' occur by applying insecticide twice monthly during the growing season, which dramatically decreases insect density (with equivalent amount of water applied to invertebrate control plots). Within these plots, we measure plant community composition and biomass, mycorrhizal root colonization, and herbivore abundances. We will add new measurements of plant population dynamics for the dominant grass species in LTER VIII.

7. Mechanisms of forb response to historical drivers – While C_4 grasses make up most of the phytomass in tallgrass prairie (Smith & Knapp 2003), C_3 forbs contribute most to plant diversity. In the absence of grazers, frequent fires reduce forb cover and richness (Collins *et al.* 1998, Koerner *et al.* 2014). Yet when large grazers are present, more-frequent fires increase forb cover and species richness (Koerner *et al.* 2014). We know little about the population dynamics of forb species that generate these responses, and the mechanisms underlying differential species responses to burning, grazing, and their interaction. To fill this gap, we will compare population growth rates of four forb species that differ in longevity and rarity in response to burning and grazing. **We hypothesize that burning and grazing will more strongly increase population growth rates for less common species (as a mechanism maintaining biodiversity in a disturbed landscape) and short-lived species (that can quickly regrow following disturbances).** We will annually census two populations of each species in grazed and ungrazed, annually burned, 2-yr and 4-yr watersheds, and fit functions for vital rates (survival, growth, seed and vegetative reproduction) that include climate, bison grazing intensity, and years since fire as predictor variables. We will use these functions to construct climate-driven integral projection models that incorporate time since fire and grazer presence or absence. We will compare predicted population growth rates across the four species to test the relative influence of grazing and burning, and to learn which vital rates govern responses to each driver.

8. Small mammal monitoring – Concerns about small mammal reservoirs of zoonotic pathogens are increasing in the US Central Plains (Han *et al.* 2015). Predictions forecast increased zoonotic potential and risk of disease for human populations living or working in the urban-grassland/woodland interface.

Pathogen distributions and prevalence respond to environmental changes, including woody encroachment of grasslands (Morlando *et al.* 2012). **We hypothesize that a transition from a grassland to woody state results in increased occurrence of small mammals that vector novel zoonotic pathogens.** During LTER VIII, we will expand small mammal sample collection to quantify the diversity of parasites, their host-associations, and the co-distribution of hosts, parasites and pathogens across the prairie-woodland mosaic. We have putatively identified three new helminth species and one new roundworm genus to date. In collaboration parasitologists at K-State Vet-Med, we are identifying tick and flea vectors using molecular methods and testing these arthropods for presence of a panel of pathogens important to humans, including Lyme's disease, *Ehrlichia*, and Rocky Mountain spotted fever. Preliminary data show much lower occurrence of vectors in native grasslands, suggesting that tallgrass prairies may offer underappreciated ecosystem services such as reduced zoonotic potential.

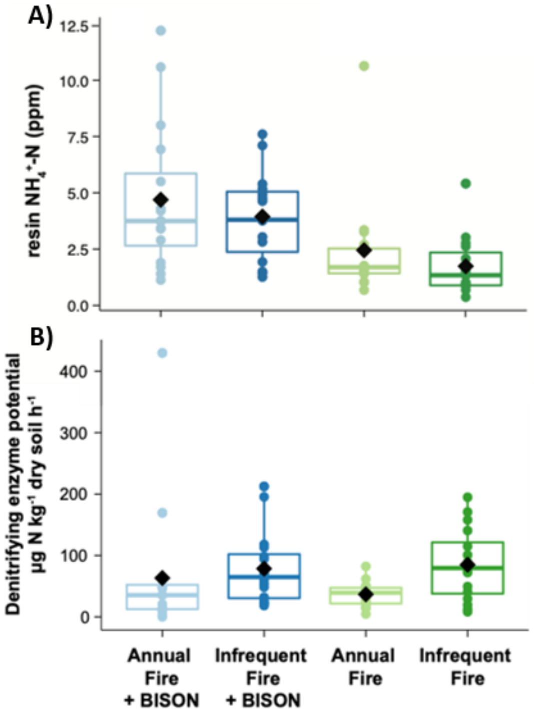

Fig. 10: A) Bison grazing increases N availability (*p*=0.0035), (B), while fire cessation increases denitrification potential (*p*=0.004). Zeglin and Allenbrand *unpublished.*

9. Soil N cycling on watersheds – Although studies at KNZ and elsewhere have documented fire- and grazing-induced changes in N availability and selected N cycling processes, there remain many unknowns, particularly following long-term vegetation state changes with infrequent burning or after long-term grazing. Existing data support the prediction that N availability and N-cycling rates are higher in both grazed and unburned prairies (Johnson & Matchett 2001), but also show that potential N loss via denitrification is significantly higher in the unburned and ungrazed state (Fig. 10). This is consistent with evidence that denitrification is often C-limited, and that both C and N accumulate with fire suppression, especially in woody-encroached areas (McKinley & Blair 2008). **We hypothesize that low fire frequency will increase N cycling and denitrification potentials as much or more than grazing, and that the threshold of fire-return interval that promotes N loss through denitrification is higher in the presence of grazers.** To evaluate this, we will measure N availability, C mineralization, soil extracellular enzyme activity, nitrification and denitrification potentials, and C and N pools in grazed and ungrazed watersheds burned at 1, 2, 4, and 20-yr frequencies. We will archive samples to enable future microbial community and population measurements. Measuring soil C and N limitation, mineralization and denitrification potential across the range of fire-interval and grazing treatments will help define the mechanisms underpinning alternate biogeochemical states.

10. Groundwater responses in watersheds undergoing ecosystem change – To project future water quality and quantity, long-term assessments that link climatic, ecosystem, and hydro-bio-geochemical processes are needed (Goddéris & Brantley 2013, Duffy *et al.* 2014, Sullivan *et al.* 2020). Long-term groundwater measurments at KNZ have revealed directional changes in groundwater depths, pH, and trace mineral concentrations coincident with changes in land cover and climate (Macpherson *et al.* 2008, Vero *et al.* 2018, Macpherson & Sullivan 2019, Sullivan *et al.* 2019). Connectivity of preferential flow paths, water storage, and biogeochemical reactions are altering the ability of the subsurface to store and release C and nutrients. During LTER VIII, we will address three hypotheses regarding the sensitivity of groundwater dynamics to changes in aboveground ecosystems. First, **we hypothesize that a transition from grassland to woodland will alter the deep (> 2 m) subsurface geochemical weathering,**

biogeochemistry, and microbial community. Second, **we hypothesize that groundwater systems are more sensitive to press** (long-term ecosystem changes) **vs. pulse** (inter-annual variability in precipitation and evapotranspiration) **dynamics, with unknown consequences for watershed hydro-biogeochemical resilience.** Finally, **we hypothesize that groundwater flow paths and biogeochemical fluxes are lagged compared to changes in surface vegetative state**. To address these hypotheses, we will continue monitoring of groundwater in a woody-encroached watershed (on-going since 1991) where groundwater pCO_2 has increased faster than $[CO_2]$ in the atmosphere, and we will expand measurements to include two adjacent watersheds where land cover differs. Water chemistry measurements will include pH, dissolved oxygen, major ions and nutrients, and archival for microbial diversity measurements. Data will be paired with aboveground biotic data and hyperspectral NEON data to correlate below- and aboveground responses over larger areas.

VI-B: <u>Experimental Manipulations</u> of Global Change Drivers to Assess Resilience

Plot-level experimental manipulations of climate and nutrients, embedded within the watershed-scale treatments of fire and grazing, provide mechanistic insight into the role of chronic “press vs. pulse” disturbance as modifiers of resilience in tallgrass prairie (Smith *et al.* 2009). Changes in drivers outside the historical range of variation may reduce resilience, making transitions to alternate states more likely (Scheffer *et al.* 2015, Ratajczak *et al.* 2018). Plot-level experiments provide the means for contextualizing

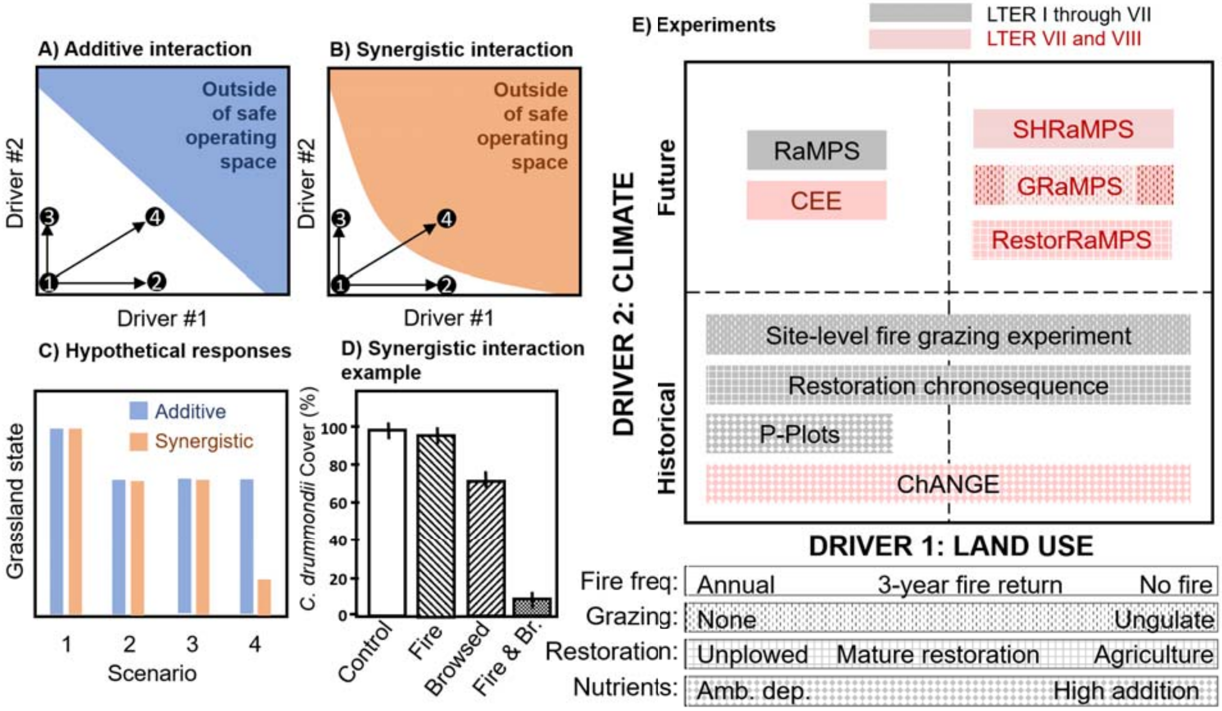

Fig. 11: Interacting drivers may change the threshold by which the historic state is maintained or shifts to an alternate state (Scheffer *et al.* 2015, Ratajczak *et al.* 2018). Interactions among drivers can take many forms, including additive (panel A) or synergistic (B). Assessment of scenarios that consider drivers individually and/or vary their magnitude (filled circles #1-3), as well as their interaction (filled circle #4), can link state changes with the type of driver interaction (panel C). Panel D provides an example of a synergistic driver interaction between fire and simulated browsing, dramatically reducing shrub cover and returning to the grassland state (redrawn from O'Connor *et al.* 2020). In panel E, we illustrate a subset of experiments that encompass this parameter space. The projects in panel E refer to: RaMPs (Knapp *et al.* 2002), CEE - project #11, Site-level fire/grazing - #1 & #2, ChANGE - #12, PPlots - #13, Restoration chronosequence - #20, SHRaMPS - #15, GRaMPS - #14, RestorRaMPS - #22 (Fig. 3).

responses to long-term variation and understanding responses to extreme events (Knapp *et al.* 2015, 2018), as well as novel interacting drivers (O'Connor *et al.* 2020). Numerous KNZ experiments have found that global change drivers can alter sensitivity to historical drivers (such as climate variability), which affects key ecosystem functions such as ANPP (Wilcox *et al.* 2016a, Collins *et al.* 2012, Manning & Baer 2018, Komatsu *et al.* 2019).

Experiments that simultaneously manipulate multiple drivers to assess ecosystem sensitivity and resilience are less common in ecology (but see examples: Milchunas & Lauenroth 1995, Reich *et al.* 2001), but can provide important insights beyond those that manipulate drivers in isolation (Komatsu *et al.* 2019). For example, concurrent shifts in multiple interactive drivers can cause abrupt system changes via additive or synergistic interactions (Scheffer *et al.* 2015, Ratajczak *et al.* 2018) (Fig. 11). When interactions among multiple drivers are additive, the likelihood of a regime shift (moving outside of a safe operating space - Rockström *et al.* 2009, Scheffer *et al.* 2015) can be calculated as the sum effect of each driver variable separately (Fig. 11A). When drivers interact synergistically, the likelihood of a regime shift increases compared to dynamics defined by additive interactions between drivers (Fig. 11B). Experiments that manipulate multiple drivers can test for additive or synergistic interactions based on functional responses or assessments of state across a range of scenarios (Fig. 11C & D).

Since its inception, KNZ LTER has initiated many experiments that manipulate land use (Driver 1: e.g., fire frequency, grazing, restoration, and nutrients in Fig 11E) within the context of the historical climate (Driver 2 in Fig 11E). Beginning in LTER IV, KNZ initiated cutting-edge rainfall manipulation experiments to simulate future climates (e.g. Knapp *et al.* 2002, Hoover *et al.* 2014), but these experiments were constrained to a single land-use (treatment). For LTER VIII, we will manipulate multiple drivers simultaneously, allowing us to identify whether drivers interact additively or synergistically, which will facilitate the exploration of safe operating space and associated resilience (Fig. 11E). These experiments are providing our first comprehensive examination of how non-climate drivers will mediate grassland responses to projected climate change, which may help inform conservation and management decisions.

CONTINUING EXPERIMENTS:

11. Climate Extremes Experiment (CEE) – While high climatic variability is a hallmark of the tallgrass prairie ecosystem (Knapp *et al.* 2017a) and grasslands more generally (Knapp & Smith 2001), predictions of future changes include increased variability in air temperatures and rainfall patterns, as well as increased frequency, magnitude and duration of climate extremes, such as droughts and floods (IPCC 2013). Extreme drought can have large impacts on ecosystem structure and function (Du *et al.* 2018), with grasslands exhibiting high sensitivity but also high resilience to these events (Hoover *et al.* 2014, Stuart-Haetjens *et al.* 2018). The effects of drought may be magnified in a future climate as they become longer and more extreme, partly due to functional loss and species turnover (Griffin-Nolan *et al.* 2019).

The Climate Extremes Experiment (CEE) investigates the effects of repeated extreme droughts and the role of drought legacies on tallgrass prairie resilience. CEE began in 2010, with extreme 2-year droughts imposed in 2010-2011, 2014-15, and 2018-2020 (Fig. 12). In 2014-15, we imposed drought on plots that previously had (D-D) and had not experienced extreme drought (C-D), and examined recovery in plots that were previously droughted (D-C) (Fig. 12B). With the first drought recovery, we found that grassland structure and function, although sensitive to drought, was highly resilient (rapid recovery to control levels). During drought, the dominant grasses increased in abundance while the dominant C_3 forb (*Solidago Canadensis*) declined (Fig. 12C, Hoover *et al.* 2014). This shift in plant composition persisted two years' post-drought, resulting in increased sensitivity to a subsequent extreme drought. Thus, plots experiencing two consecutive droughts (D-D) experienced the greatest loss in function with drought (Fig. 12C). Despite greater sensitivity, the legacy of first drought did not influence resilience to the second drought (Fig. 12C).

In LTER VIII, we will impose the third, and most extreme drought (initiated in 2018) on all of the plots in CEE to examine how the legacy of 0-, 1- and 2- extreme droughts affects tallgrass prairie sensitivity and resilience. The CEE allows us to assess legacies of droughts and the potential carry-over between events that affect sensitivity and resilience. **We hypothesize that legacy effects from prior droughts will increase sensitivity to the most recent extreme drought (magnitude and duration), and we anticipate a potential state transition if the mortality threshold for C_4 grasses is exceeded.** We anticipate that with insufficient recovery as a result of repeated drought, the third extreme drought will erode the resilience of the C_4 plant community leading to a transition to a degraded state. State change will be quantified by measuring ANPP, soil respiration, plant composition and population abundances.

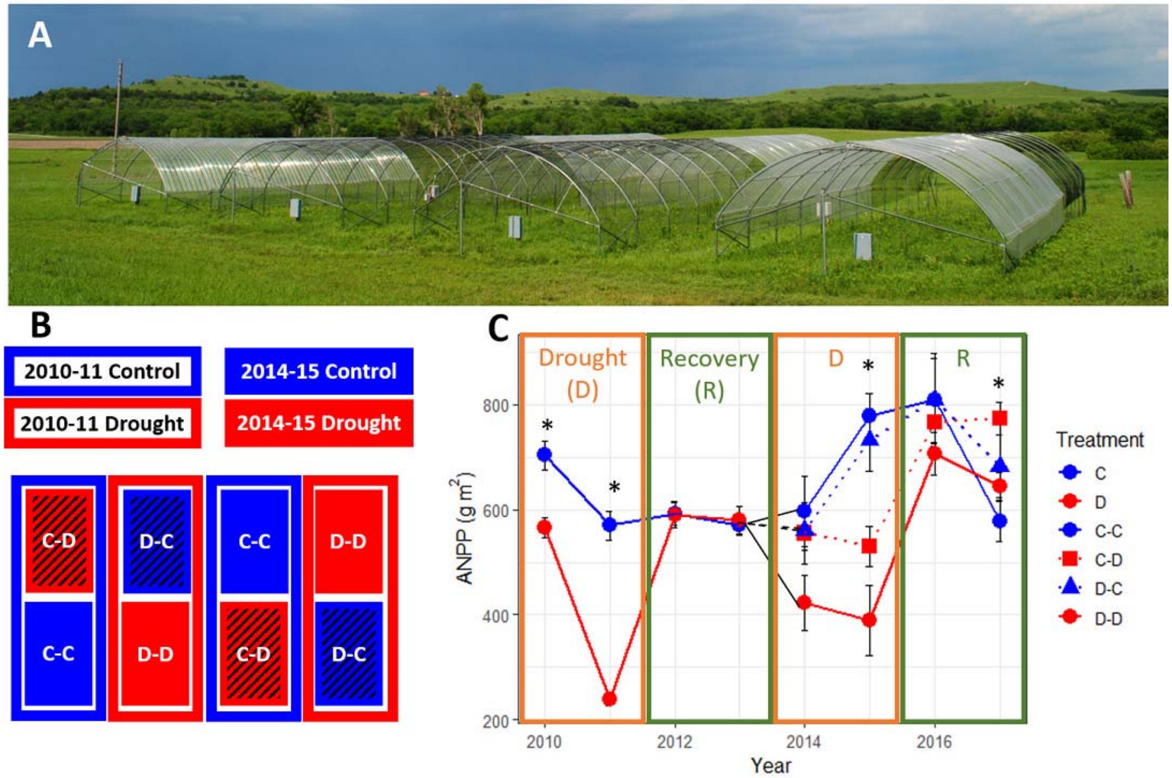

Fig. 12: A) The Climate Extremes Experiment. B) In 2010/2011, two shelters were droughted and two were controls. Control (ambient precipitation) plots ("C") are shown in blue and droughted plots ("D") in red. 2012/2013 were recovery years. In 2014/2015 drought shelters were split in half (shown in 12B). Treatments for the second drought were: previously control-control (C-C, solid blue), previously control-droughted (C-D, solid red), previously droughted-control (D-C, hashed blue), and previously droughted-droughted (D-D, hashed red). 2015/2017 were recovery years. In 2018, a three-year exceptional drought was started for all treatments. C) ANPP responses to the first two droughts and recovery periods. Asterisks denote significant differences between treatments in a given year.

12. Chronic Addition of Nitrogen Gradient Experiment (ChANGE) – Anthropogenic changes in nutrients are occurring globally (Vitousek *et al.* 1997, Smith *et al.* 2009). Human activities have greatly elevated N deposition (Vitousek & Howarth 1991, Gruber & Galloway 2008). Nitrogen fertilization can increase ANPP in terrestrial and aquatic systems (Stevens *et al.* 2015) and creates novel conditions that differentially favor some species at the expense of others, leading to declines in biodiversity and altered plant communities (Stevens *et al.* 2004, Lebauer & Treseder 2008, Harpole *et al.* 2016, Tatarko & Knops 2018). In addition, excess nutrient accumulation can have compounding effects as resources accumulate over time (Smith *et al.* 2009).

In 2013, we established ChANGE to assess the sensitivity of tallgrass prairie plant community and ecosystem function to a gradient of chronic N additions, from projected low levels of N deposition to levels used in other experiments (e.g., P-Plots, the Belowground Plot Experiment), up to more extreme levels reflecting agricultural inputs. N has been added annually at 0, 2.5, 5, 10, 15, 20, 25, 30 g m^{-2} since 2014. Plant species composition and ANPP have been measured each year to assess ecosystem responses within the HRF (Smith *et al.* 2009). To date, N addition of $\geq$ 5 g m^{-2} increases ANPP in years with average to above-average growing season precipitation, but surprisingly no changes in plant diversity or community composition have been observed yet at any level of N. The treatment duration may not yet be sufficient to capture community change (> 10 years, Komatsu *et al.* 2019), or shifts may require interactions with other drivers or a climatically or biotically unusual year coupled with N fertilization may be necessary for a shift in a plant community composition (see: Ratajczak *et al.* 2019).

In LTER VIII, we plan to impose both a new deluge treatment (water addition representing a 1:100-year high rainfall) and a grasshopper density manipulation (using small enclosures) across the gradient of N additions. Together these new manipulations will allow us to address questions about the nature of the interaction between these pulse-press drivers and whether this interaction leads to regime shifts (Fig. 5B). **We hypothesize that synergistic interactions among multiple drivers (more N, altered rainfall and herbivory) will accelerate plant community changes, with cascading large responses in ANPP for altered plant communities**. In addition to testing the HRF (Smith et al. 2009), this project will assess thresholds of individual plant species' responses to the gradient of N addition over time, allowing an independent test of Tilman's resource ratio hypothesis (Tilman 1982) in a grassland system.

13. *Phosphorus Plots Experiment (P-Plots)* – Both N and P availability can limit ecosystem function globally (Du *et al.* 2020). However, the effects of N enrichment on terrestrial plant community composition and function have received far more attention than P enrichment, and the interactive effect of both may exacerbate diversity loss over time. The P-Plots experiment (2002-present) factorially manipulates N and P to assess impacts on plant community composition and production. To date, we have found that N or P additions alone have little effect on plant community composition, but N and P together result in reduced abundance of C_4 grasses and increased abundance of non-N-fixing and annual forbs (Avolio *et al.* 2014). Concurrent N and P additions also caused the species composition of replicates within a treatment to become more spatially heterogeneous resulting in greater variability in ANPP (Koerner *et al.* 2016).

In LTER VIII, we will assess how climate variation interacts with the spatial heterogeneity among replicate plots and measure the consequences of nutrient-induced plant community composition shifts on the resilience to inter-annual variability in precipitation. **We hypothesize that inter-annual climate variation will modulate the heterogeneity of plant communities in the N and P- enriched treatments.** We expect that drought will homogenize the replicates within a treatment by increasing the dominance of C_4 grasses, while variability among replicates will increase during wet years as different ruderal species become abundant in different microhabitats. **We also hypothesize that chronic high levels of nutrient addition will reduce resilience of plant communities to drought, because of their effects on plant community composition.** Our prediction is that plant communities dominated by C_4 grasses will be more resilient than those dominated by annual and non-N-fixing forbs. We will leverage the 2012 and 2018 droughts, the 2019 high-rainfall year, and upcoming climatic extremes to address these questions.

NEW LTER VIII EXPERIMENTS:

14. Grazing x rainfall manipulations plots (GRaMPs) –A majority of global circulation models project that the occurrence of multi-year droughts will increase by the mid-21st century in the Central Great Plains (Cook *et al.* 2015). The discrete effects of grazing and precipitation are well-established at KNZ, but these two drivers may also interactively impact grassland communities. Grazers are integral to the evolutionary history of prairies, and cattle are the dominant large grazer in most modern mesic grasslands. Drought can modify the impact of grazing (Louthan *et al.* 2018), meaning that studying non-grazed grassland may be inadequate for projecting tallgrass prairie resilience to climate change. For example, Koerner & Collins (2014) found that the concurrent impacts of simulated grazing (i.e., clipping) and experimental rainfall manipulation resulted in steeper declines in grass stem density than either factor alone. These studies suggest that future climate change could cause stronger grazing effects on plant populations and community resilience.

Currently, no long-term studies at KNZ address how climate change, including climate extremes, will affect plant communities in grazed areas (Fig. 11). We will establish drought shelters (each ~6 x 6 m in size) in bison grazed watersheds by repurposing shelters from a previous Macrosystems study (EDGE: Griffin-Nolan *et al.* 2019). These shelters will passively impose an extended, extreme drought (50% rainfall reduction) for three years, allowing us to examine interactive effects of past grazing history and drought on plant performance, community composition, and resilience. Perimeter fences will prevent grazer access to shelters during the experiment, because shelters may artificially attract or deter grazers, leading to unrealistic grazing pressures. Instead, grazing will be simulated by clipping vegetation to mimic grazing rates approximated during the 2012 extreme drought (Raynor *et al.* 2015). As a control, 10 more shelters will be located on a nearby ungrazed watershed with the same fire frequency.

We hypothesize that the effects of grazing history and clipping on plant populations, community structure, and ecosystem function in bison-grazed watersheds will be higher under drought vs. ambient conditions. Specifically, we predict that the droughted, historically 'grazed' treatment will shift to a lower ANPP state with higher xeric shortgrass species abundance than either the droughted or grazed only treatments. At the individual level, grazed *A. gerardii* allocates fewer resources to root growth (Nippert *et al.* 2012) reducing potential water uptake, resulting in lower performance in drought. At the ecosystem-level however, grazed areas could show higher resilience than ungrazed, much like the response following the Dust Bowl drought of the 1930s (Weaver & Albertson 1956). Together, GRaMPs and EDGE (Griffin-Nolan *et al.* 2019) will comprise a comparative design manipulating bison ‘grazing’ and the presence/absence of extreme drought. We will use these experiments to quantify the relative and interactive effects of drought and grazing and predict how the impact of bison grazing might change grassland structure and function under more variable future climate conditions.

15. Shrub rainfall manipulation plots (ShRaMPs) – Drought and woody encroachment are likely to have interacting effects on grassland dynamics, but we know little about these interactions. Most climate manipulations at KNZ and other grasslands have been done in grass-dominated areas, and knowledge gaps exist for core attributes, such as plant physiological functioning, changes in plant composition, and altered biogeochemistry, limiting our ability to predict response of grassland processes to changes in both climate and woody plant cover. In 2017, we built 14 large rainout shelters (each ~6 x 6 m) over established *Cornus drummondii* clonal shrub islands, and in 2018, we began experimental droughts by reducing annual precipitation by 50%. To incorporate the role of fire as a driver of these dynamics, shelters were built on watersheds with significant woody encroachment, but now with different fire frequencies (1-yr and 4-yr). *Note: both watersheds were historically 4-yr burns allowing woody encroachment. In 2011, the watershed K4A switched to an annual fire frequency.* **We hypothesize that drought will shift root biomass allocation patterns in both grasses and shrubs, with grasses increasing deeper root biomass and shrubs increasing total root biomass throughout the soil profile. Overall, these shifts will intensify competition between grasses and shrubs for soil moisture**. Plant stress will be assessed by measuring physiological and morphological traits (leaf water potential, gas exchange, leaf carbon isotope composition (shrub only), leaf osmotic potential) and whole-plant traits (biomass, stem density, cover, and plant richness).

VI-C: <u>Cessation / Reversal of Drivers</u> to investigate community assembly processes, legacies and hysteresis

Chronic environmental change can drive a system to an alternative state, but persistence of the new state may depend on maintenance of the external driver, rather than on inherent stability. If the alternative ecosystem state is difficult to reverse (i.e., exhibits hysteresis), then resilience of the original state has been lost (Scheffer *et al.* 2009, Petraitus 2014). Experiments that reverse or cease external drivers are excellent tests for determining if an alternative stable state transition has occurred, by enabling empirical assessment of the strength of hysteresis (Bestelmeyer *et al.* 2011, Ratajczak *et al.* 2018). Legacies of functional responses or community change can delay, constrain, or alter trajectories of recovery (Johnstone *et al.* 2016), and serve as the feedbacks that maintain alternative states. For example, consider a change in fire frequency from annual to long-term fire suppression, resulting in a transition from a grassland to woodland state (Fig. 6). If resuming annual fires fails to reverse woody plant expansion, it is likely that grassland and woodland represent alternative stable states (Fig. 5C). In tallgrass prairie, and other ecosystems, slow ecological change necessitates long-term reversal experiments to generate robust conclusions (Bestelmeyer *et al.* 2011). In LTER VIII, we build upon recently initiated driver reversals, and add a new fire reversal in grazed prairie, to improve our understanding of driver interactions (Fig. 11) and help identify mechanisms that maintain alternative grassland ecosystem states (Fig. 4).

CONTINUING EXPERIMENTS:

16. Irrigation Transects – The Irrigation Transect experiment was initiated in 1991 to understand the effects of water limitation on tallgrass prairie structure and function. A set of transects spanning upland and lowland sites are either irrigated during the growing season to alleviate water limitation, or left unirrigated. After ~20 yrs, irrigation increased ANPP beyond levels predicted by the inter-annual relationship of precipitation and productivity at KNZ (Wilcox *et al.* 2016a). This unexpected increase in ANPP was due to a shift in plant dominance by a more productive C_4 grass species, *Panicum virgatum*, that was not originally abundant in the community (Collins *et al.* 2012, Wilcox *et al.* 2016a). In 2017, we reciprocally reversed treatments on a subset of historically irrigated and control plots, allowing us to quantify hysteresis. We also added a new extreme drought treatment to plots that were either historically irrigated or experienced ambient rainfall, designed to identify legacy effects of 25 years of supplemental water and assess how legacies affect the sensitivity of tallgrass prairie to climate variability and drought. Maintaining a subset of plots under the original treatments also allows us to continue assessing longer-term responses to a chronic change in water availability. **We hypothesize that continued alleviation of water stress will maintain the trajectory towards *Panicum* dominance, though other resource limitations may favor new species changes, and that the legacy of past climatic conditions will alter climate sensitivity such that communities assembled under chronic irrigation are more sensitive to future droughts**. To address these predictions, we will continue to measure ANPP, plant species composition, total soil C and N, soil CO_2 flux, net N mineralization, microbial biomass C and N, root biomass, and root litter decomposition in all treatments.

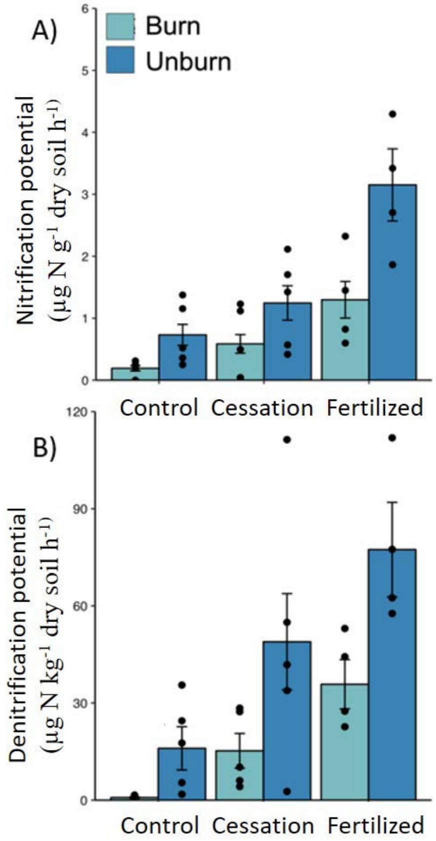

Fig. 13: N cessation decreased nitrification but not denitrification, and rates are higher in the unburned ecosystem state (Nieland *et al.*, in review).

17. Belowground Plots Experiment – Globally, and at KNZ, atmospheric N deposition has increased. Changing fire regimes have also shifted N dynamics, with fire suppression promoting soil N accumulation. Higher N availability can alter both plant and soil microbial community composition (Wilson *et al.* 2009, Coolon *et al.* 2013, Carson *et al.* 2019), and other biotic processes including higher ANPP, N assimilation, and nitrification and denitrification potentials. Thus, burning of N-containing plant litter (Isbell *et al.* 2013), and soil microbial activity promoting leaching and gaseous N flux, can both cause loss of excess N from chronically fertilized ecosystems. Whether these losses can counteract long-term accrual of N in the soil organic matter pool (Lovett *et al.* 2018) is unresolved. Increases in plant growth and microbial N cycling following N addition are well documented, but the processes leading to N loss after cessation of long-term fertilization are less clear (but see Clark & Tilman 2010 for changes in N availability). Because these changes will determine the overall trajectory of ecosystem recovery to a low-N state, it is essential to understand their rates of recovery over time.

In 2017, we ceased fertilization in the Belowground Plots (BGP) experiment (1986-present). After 30 yrs of N fertilization (10 g N m^{-2} y^{-1} as ammonium nitrate), plant production, microbial community structure, bacterial populations and denitrifier populations were resilient to the loss of fertilizer after one growing season; however, potential activity of nitrifiers and denitrification potential rates recovered (Fig. 13). In addition, the higher denitrification potential in the unburned treatments indicates the importance of alternate biogeochemical states in response to changes in fire frequency. **We hypothesize that recovery from N enrichment in the absence of fire is mediated by microbial processes while fire-induced losses of N will drive recovery rates with annual burning.** In LTER VIII, we will continue measurements of ANPP, and also measure soil C and N pools, N cycling potentials and microbial community structure and functional gene abundance to assess the trajectory of ecosystem recovery in these treatments. Five years post N cessation (2021), we will collect plant tissues, litterfall, and soil water to better constrain an N budget and disentangle the mechanisms that result in loss of excess N in the recovering burned and unburned ecosystem states.

18. Fire Reversal Experiment – Infrequent burning (>3 years between fires) results in transitions from herbaceous tallgrass prairie to a system dominated by trees and tall shrubs (Fig. 6) (Ratajczak *et al.* 2014a, Veach *et al.* 2014). On the other hand, annual burning in areas without grazers results in a low-diversity community dominated by a small number of C_4 grass species (Collins & Calabrese 2012). To test the resilience of these grassland states to changes in fire frequency, the fire reversal experiment (2000-present) changed two ungrazed watersheds that had been burned annually for decades to a 20-year fire frequency, and two watersheds with a history of infrequent burning (~20-yr fire frequency) to annual burning. A goal of this experiment is to determine *if and how rapidly* altering fire frequency changes plant communities and ecosystem processes, after long-term changes in vegetation have already occurred. To date, the reduction in woody plant cover in response to two decades of annual fire has been limited (Collins *et al.* unpublished). In the 20-year fire reversal, grass dominance was stable for the first eight years following fire suppression, but began to decrease rapidly in year nine of the experiment, with a ~40% decrease in grass cover from 2008-13 (Fig. 14, Ratajczak *et al.* 2017b, Collins *et al.* unpublished). In the original 20-year fire year treatment (020b) a similar decline in grass cover preceded a rapid increase in shrub cover (Ratajczak *et al.* 2014a). In LTER VIII, **we hypothesize that following an initial lag phase, an increase in woody plant cover with reduced fire frequency will occur more rapidly than the loss of woody species with increased in fire frequency**. We will continue to assess whether reliable “early warning signs” precede difficult to reverse transitions in plant communities. During LTER VII, we used a simulation model to show that increased spatial variability

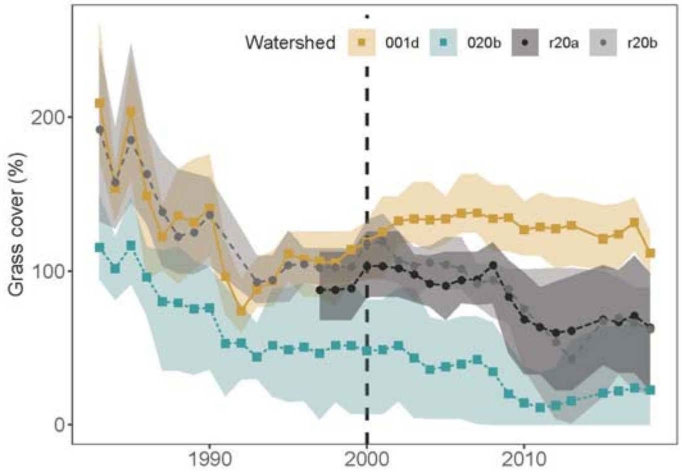

Fig. 14: Changes in grass cover (1983-2018) in a watershed burned each year (001d), once every 20 years (020b), and replicate watersheds burned annually until 2000 and once since year 2000 (r20a, r20b). Points indicate mean cover while shading indicates 95% CI. Data from PVC02, updated from Ratajczak *et al.* 2017a.

preceded state changes, and that when this warning sign is apparent, timely reversals of drivers can be used to halt the regime shifts (Ratajczak *et al.* 2017b). However, such theoretically derived warning signs have rarely been tested with experiments, especially in terrestrial ecosystems (Hastings & Wysham 2010, Scheffer *et al.* 2015). In LTER VIII, we will continue to test whether increases in spatial variability and other theoretically derived warning signs are reliable indicators of regime shifts (Scheffer *et al.* 2015).

NEW LTER VIII EXPERIMENTS:

19. Fire Reversal in the Presence of Grazers – Results from the Fire Reversal experiment show that, thus far, grass- to woodland transitions are difficult to reverse by manipulating a single driver, such as reinstating annual fires (Ratajczak *et al.* 2017a, b). Grassland-to-woodland transitions also occur under infrequent fire frequency in bison-grazed watersheds (Briggs *et al.* 2005, Veach *et al.* 2014), and there are strong interactions between fire frequency and grazers that may play a role in these state transitions. For example, bison prefer grassy areas, and site use by bison increases following fire (Knapp *et al.* 1999, Raynor *et al.* 2015, 2017a). However, it is unclear if bison grazing responds similarly in grasslands that have undergone woody encroachment and, if so, whether the combined effects of multiple drivers (increased fire frequency and increased grazing) enhances or impedes the recovery of the grassland state (e.g., Fig 11a vs. 11b). This has important implications from both theoretical and management perspectives: Does changing multiple drivers facilitate recovery of an alternate state, and can fire and grazing be altered to achieve management goals?

To assess the combined effects of increased fire frequency and grazing on plant community composition, woody plant dynamics, and ecosystem processes, we will initiate a new experiment in two bison grazed watersheds with a history of long-term fire suppression and substantial woody plant encroachment (Fig. 6; >40% woody plant cover [Ratajczak *et al.* 2014a]). **We hypothesize that bison will increase site use in response to more frequent burning of former 20-yr fire treatments, but the net effect of fire and bison will depend on how the balance of grazing (removal of grass and reduced fuel loads) and non-grazing (trampling, wallowing) activities impact plant communities and competition between grasses and woody plants**. To assess fire-grazing interactions, we will establish six 200-m^2 replicate bison exclosures per watershed in areas that have undergone grassland-to-woodland conversion, each paired with a plot left open to grazing. To assess changes in bison behavior and use, smart ear-tag technology (Kraal Farms, Inc.) will allow us to track bison movement and monitor individual behavior (time spent grazing vs. resting vs. walking), so that we can quantify bison foraging preferences in relation to fire frequency and history. We will examine the potential for differential responses among individuals by tagging different age and sex classes. We will measure plant community composition, woody cover and stem density, and herbaceous biomass in 2020 prior to initiating new annual spring burning treatments in 2021 and continue these measurements for the foreseeable future. These data will be used to add bison effects to our spatially-explicit simulation of fire-grass-shrub-interactions (Ratajczak et al. 2017a). Further, one of these grazed reversal watersheds has water chemistry and discharge data collected since 1987, allowing us to assess hydrological and geochemical responses to this fire reversal.

VI-D: Human Intervention

There is an escalating need to manage processes that maintain and promote species diversity and desired ecosystem states, as human-driven environmental change continues to degrade ecosystems and reduce biodiversity (Vitousek *et al.* 1997, MacDougall *et al.* 2013). Two major state changes in grasslands globally are conversion to cultivated cropland (Ellis & Ramankutty 2008) and transition to shrubland or woodland (Briggs *et al.* 2005, McKinley *et al.* 2008, Twidwell *et al.* 2013). As a result, temperate grassland ranks highest globally in the ratio of converted to protected area (Hoekstra *et al.* 2005). Unlike conversion to cropland agriculture, a shift from grassland to woodland is a less abrupt state change, but both have thresholds that once passed, prevent historical drivers (i.e., fire) from restoring a grassland state (Briggs *et al.* 2005, Ratajczak *et al.* 2014a, b). In both cases, reversing the state change back to one representative of native prairie requires human intervention (Hobbs *et al.* 2011).

State transitions that require human intervention to reverse can be rapid (i.e., conversion to cropland, <1 yr) or occur over long periods (grassland to shrubland / woodland, ~20 yr) (Smith *et al.* 2009, Hughes *et al.* 2013, Ratajczak *et al.* 2017a, b). These non-grassland states can generate ecological legacies that constrain recovery of a grassland state. As such, restoration often involves direct manipulation of legacies. Current and proposed LTER VIII projects using human intervention to induce a state change include restorations of agricultural land, stream connectivity, and riparian areas via woody removal.

CONTINUING EXPERIMENTS:

20. Sequential Restoration Plots – We initiated a long-term sequential restoration experiment in LTER VI to reveal how deterministic and stochastic factors (e.g., inter-annual climate variability) affect community development trajectories and recovery of soil properties and processes over decades. **Our hypothesis is that community assembly is largely deterministic over the long term, but stochastic events (e.g., drought) slow restoration of prairie communities by prolonging transient ruderal states.** To test this hypothesis, we sequentially restored blocks of prairie in an agricultural field every two years using the same species and live seeding rate (deterministic factors), but under different starting conditions due to natural inter-annual variability in climate, seed banks, soil conditions, etc. (stochastic factors). Each sequence (SEQ) consists of four 20 m x 20 m blocks of restored prairie. Seeds are continuously collected at KNZ, processed, and analyzed for live seed content. Three sequences were installed during LTER VI (SEQs I-III) and LTER VII (SEQs IV-VI). We will install the final sequence by 2022. With LTER VIII, there will be 7 sequences spanning 12 establishment years, with time series data on plant communities, ANPP, and soil C and N ranging from 1-5 yrs in SEQ VII to 1-18 yrs in SEQ I.

Climate during the initial growing seasons of the restoration sequence has been highly variable. For example, SEQ I was established under 'average' precipitation conditions, whereas SEQ II (in 2012) and SEQ VI (in 2018) were established during severe droughts. Trajectories of community development during the first three years of restoration differed for sequences initiated under average precipitation and drought (Manning & Baer 2018). During LTER VIII, we will analyze longer-term community trajectories across all establishment years, spanning a range of starting conditions, to examine whether there is a relationship between climate at seeding time, transient ruderal states, and long-term outcomes (Fig. 15). Because drought is often transient and can result in a positive legacy effect (Griffin-Nolan *et al.* 2018), we established rainout shelters at the onset of restoration in 2018 to impose continuous drought. **We hypothesize that continuous drought will result in communities dominated by volunteer, drought tolerant, ruderal species delaying the development of the native grassland state**. Plant community composition and ANPP responses to continuous drought in the 2018 sequence will be compared to data

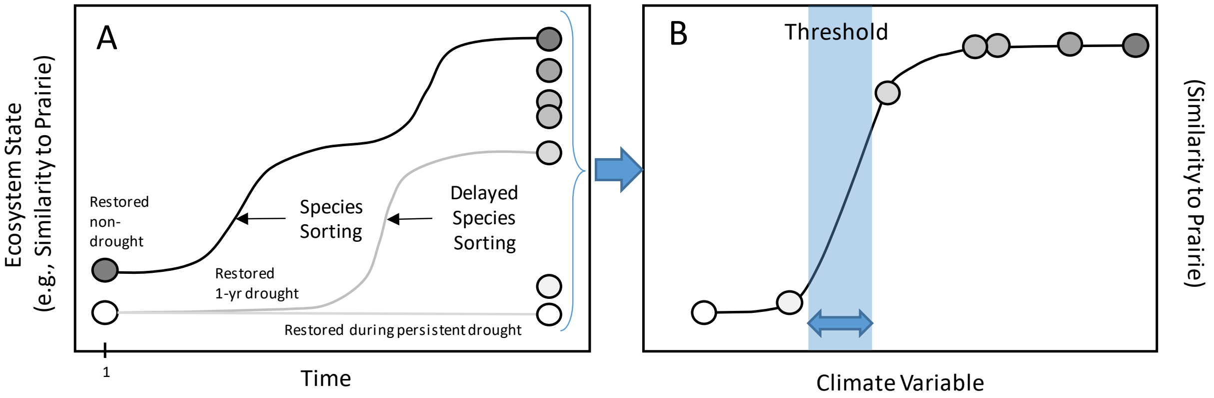

Fig. 15. (A) Hypothesized influence of climate in the initial restoration year on community sorting from ruderal to restored states similar to native prairie. (B) A hypothesized relationship between restored prairie similarity to native prairie and a climate variable in the restoration year depicting a threshold in the climate variable needed to achieve a state that resembles native prairie.

from sequences initiated under average precipitation and drought years to assess the role of climate as a potential overriding influence on community assembly and ecosystem states in restored grasslands.

21. Woody riparian removal – Woody encroachment in riparian zones at KNZ has increased over the past 40 yrs, with some patterns dating to the 1930s (Veach *et al.* 2014). Riparian woody expansion is occurring even in frequently burned (< 2 yrs) watersheds, indicating human intervention is necessary to counter this conversion to woodland streams (Veach *et al.* 2015). Small scale (~50 m^2 plots) woody removal experiments and comparisons with wooded and grassy riparian zones revealed that woody removals decrease expansion and increase stream metabolic rates (Riley & Dodds 2012), stream invertebrate densities (Vandermyde & Whiles 2015), rates of N cycling (Reisinger *et al.* 2013), and alter microbial community structure (Veach *et al.* 2015). However, these experiments did not explore potential feedbacks between hydrology, biogeochemical transport, and geomorphology across the watershed. To address this, we initiated a whole-watershed riparian removal on a grazed 2-yr burn watershed in 2010/11 with subsequent annual mechanical removal to control woody regrowth. For the first 3 yrs, stream nitrate concentrations increased substantially, but discharge and primary production did not (Larson *et al.* 2019). A longer record is required to assess changes in hydrology and geomorphology. Since the woody removal, water isotopes from vegetation, groundwater, precipitation, and stream water suggest preferential flow paths (macropores) created by deep-rooted woody vegetation facilitate precipitation bypass of the stream aquifer (Keen *et al.* in review). **We hypothesize that woody plant removal creates macro-pores as tree and shrub roots decompose, leading to increased surface flow bypass of the stream channel and longer-term groundwater storage.** Thus, woody encroachment may create indirect legacies, even when removed. We will use long-term records of streamflow and water chemistry to assess resilience to woody removal, and assess how much of this resilience is due to flow duration and timing. Re-survey of channel geomorphology will indicate if woody removal has reversed the effects of tree roots on the channel. We will also add water chemistry sampling downstream of a site with removal of upland shrubs (K20A) to compare upland and riparian woody removal effects on streams. Finally, measurement of plant community composition before the removal will be repeated to assess how vegetation has changed in response to mechanical removals of woody plants (since 2010/11).

NEW LTER VIII EXPERIMENTS:

22. Restoration Rainfall Manipulation Plots (RestorRaMPs) – In LTER VIII, the sequential restoration project will be used to compare sensitivity and resilience of relatively mature, 12-yr restored prairie and

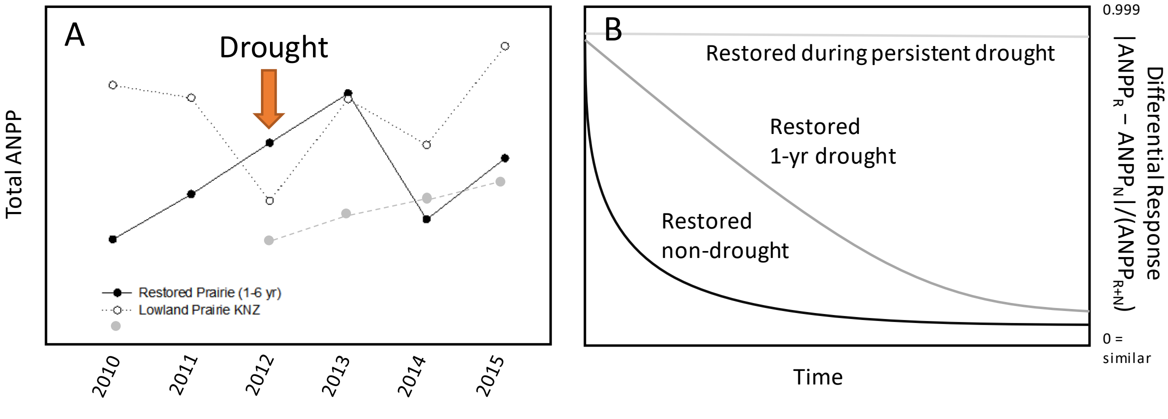

Fig. 16. (A) Total ANPP in prairie restored under average precipitation (SEQ I) and annually burned lowland prairie from 2010 through 2015 demonstrating insensitivity of restored prairie to the 2012 drought. Prairie restored under drought conditions is hypothesized to have slower and lower recovery of ANPP and delayed synchrony in ANPP dynamics. (B) Hypothesized relationships between normalized differential ANPP response in restored and native prairie when prairie is restored in non-drought, transient drought, and persistent drought conditions.

native lowland prairie to a persistent multi-year drought using 9 m^2 rainout shelters, and to assess if resilience in restored prairie matches that of native prairie (Fig. 16). **We hypothesize that native prairie is more resilient than restored prairie to drought due to higher species richness and complementarity**. We will establish rainout shelters in the oldest restoration (SEQ I) and native prairie subject to the same historic drivers (annual fire and ungrazed). Plant community composition and ANPP will be compared between 12-yr restored and native prairie treatments with and without 80% rainfall reduction for 5 years.

To predict when resilience becomes similar to native prairie, we will compare 2010-2025 ANPP (measured at the same scale) in lowland, annually burned prairie adjacent to the sequential restorations (project #20). **We hypothesize restored prairie ANPP will *not* be sensitive to rainfall during the initial establishment years when species sorting occurs** (Fig. 16) **but will track native prairie responses and exhibit resilience to drought demonstrated by positive drought legacy effects** (Griffin-Nolan *et al.* 2018) (Fig. 16). Stability and similarity to native prairie will occur when sown species become dominant in restored communities. Further, **we hypothesize that development of resilience to drought will be delayed if drought occurs early in the community assembly process**.

23. Restoring Grassland Stream Connectivity – Fragmentation of dendritic stream networks decreases resilience of stream fish communities by blocking dispersal among mainstem and tributary branches (Gido *et al.* 2016). Fragmentation, combined with increasing drought severity, can have devastating impacts on stream fishes (Perkin *et al.* 2017). Long-term sampling of fish communities upstream of an artificial barrier that fragmented the network indicated declining abundance and diversity over the past two decades, associated with reduced stream flow and accentuated mortality after the severe drought of 2018. **We hypothesize that artificial barriers inhibit the colonization of fishes from downstream refugia, resulting in decreased resilience of prairie fish communities to drought.** In LTER VII, we conducted a tagging experiment (2015-2018) to quantify annual dispersal rates of fishes above and below the barrier. Prior to removal, ~20-40% of tagged fish dispersed upstream to the barrier, but no further. In 2019 after a severe drought extirpated all fish upstream, 7% of tagged fish were detected upstream following barrier removal. We will continue tagging fish to quantifying post-drought dispersal rates in 2020 and 2021 and survey fish communities at the fragmented site and a paired non-fragmented site to compare the effects of fragmentation on resilience of prairie stream fishes to extreme drought.

VI-E: Synthesis

KNZ data and investigators are involved in many synthetic analyses and publications each year. These range from integrating multiple datasets from our archives (e.g., Bruckerhoff *et al.* 2020, Smith *et al.* 2020, Welti *et al*. 2020), those involving collaborations with other LTER sites (e.g., Ratajczak *et al.* 2017b, Collins *et al.* 2018), and others addressing ecological questions across biomes and continents (e.g., Smith *et al.* 2016, Wilcox *et al.* 2017a, Koerner *et al.* 2018, Komatsu *et al.* 2019). Three distinct elements of the KNZ program facilitate integration and synthesis: 1) our long-term datasets embedded within the landscape design of fire and grazing; 2) our legacies of short- and long-term experimental manipulations of drivers to test ecological theory and predict responses to global change; and 3) our conceptual model that encapsulates elements 1 and 2 to assess changes in grassland sensitivity and resilience from historical and global change drivers. Synergy among these core elements of our program facilitates discovery. KNZ scientists promote integration and synthesis through regular interactions, including bi-weekly ZOOM meetings (including local and non-local investigators) and an annual KNZ meeting with research presentations. For the last 3 yrs, we have organized and supported winter synthesis meetings to conduct meta-analyses using our long-term data (e.g., Knapp *et al.* 2018). In addition, we have been facilitating synthetic modeling exercises using long-term KNZ data within graduate courses at KSU.

Data integration – The mid-site review challenged us to develop approaches to integrate across scales of organization using KNZ datasets. To begin addressing this “grand challenge” we will construct statistical models that integrate (share information) across multiple data sets in LTER VIII. Integrative work to date has focused on correlative inference (regression models; e.g., Bruckerhoff *et al.* 2020), but mechanistic models based on fundamental ecological theory (e.g., May 2001; Hefley *et al.* 2017) can be developed to facilitate data integration (Fig. 17). Hierarchical Bayesian modelling provides a framework for constructing coupled theory-based models that integrate across multiple data sets (Hefley *et al.* 2017; Fletcher *et al.* 2019). At KNZ, this might include coupled responses of different taxa from our core data sets. For example, increased rainfall could stimulate plant biomass, which elicits greater grasshopper densities, leading to higher bird densities. Building hierarchical models that include linked responses across taxa (black arrows in Fig. 17) will allow us to better explain spatiotemporal variation in KNZ core responses by "borrowing strength" across taxa. The main purpose of developing hierarchical models based on ecological theory is to forecast how multiple taxa respond to gradients of land use/land cover as well as climate variability. This approach provides the potential to develop a more mechanistic understanding of food web interactions while maximizing forecast accuracy by allowing responses of co-occurring and co-varying taxa to inform the estimated responses of the other. This approach combines multiple data sets, including exogenous and endogenous drivers, and will refine our understanding of linkages across spatial and temporal scales, as well as scales of biological organization.

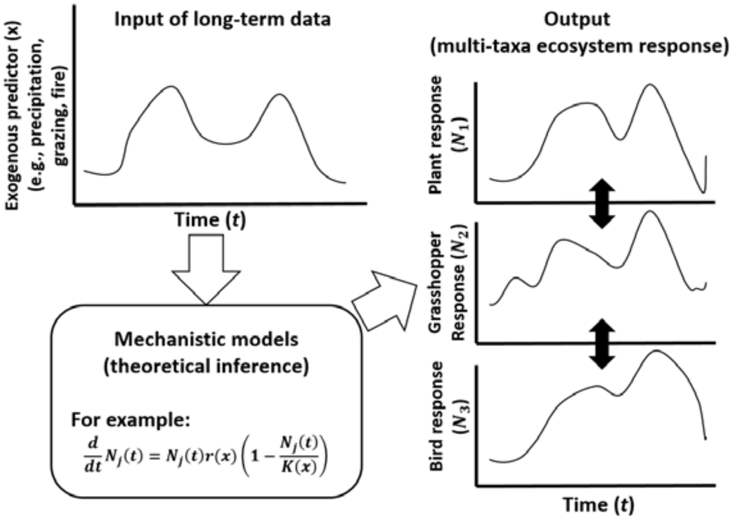

Fig. 17: Integrative modeling framework that will synthesize multiple KNZ datasets using different forms of inference to link exogenous (e.g., climate) and endogenous (e.g., species interactions; black arrows) drivers to predict and forecast spatio-temporal variation in consumer populations, communities, and ecosystem processes.

VII: Related Research Projects

KNZ will continue to leverage many externally-funded projects to complement and extend the research themes in this renewal. These projects include participation in international networks (Drought-Net, NutNet, GEx (Grazing Exclosure experiment)), regional cross-site projects (EDGE NSF-Macrosystems Project), and site-specific experiments that span LTER sites. A new NSF-Macrosystems award (Nippert) organizes grassland vegetation around phylogeny-driven functional diversity to improve Earth system model (ELMv1, E3SM) predictions. This project will include new data collection at KNZ, CDR, JRN, and SEV. A KS EPSCoR RII Track 1 project ("Microbiomes of Aquatic, Plant, and Soil Systems (MAPS)" Dodds & Zeglin) connects feedbacks and linkages within and among plants, soils, and river networks across the Kansas precipitation gradient. KNZ hosts several core sites. This research will illuminate the role of microbiomes in restoration, linkages between terrestrial and aquatic habitats, and link land uses to downstream systems. A new NSF-CAREER grant (Zeglin) will evaluate how bison and cattle grazing affect soil microbial communities and N-cycling processes across the Flint Hills. Finally, using a new USDA-AFRI award (Koerner, Avolio, Komatsu, Wilcox, & Zeglin), we will explore patch-burn grazing influences on cattle production and ecosystem services such as carbon cycling, soil health, and biodiversity at KNZ and other sites. These projects supplement core KNZ objectives and, importantly, regionalize KNZ efforts.

Multiple new site-based projects contribute to LTER VIII goals. A recent NSF-DEB award (Boyle & Hefley) aims to disentangle the importance of local and continental processes for migratory birds in an open system, something that has not previously been possible due to lack of data representing inter-annual climate variation and methods that infer animal movements, and deficiencies in statistical methods (Grosbois *et al.* 2008). A DOE-BER grant (Nippert, Zeglin & Wilcox), will identify the feedbacks of drought and woody encroachment on belowground root architecture, soil microbial C cycling, and ecosystem C balance. These data will parameterize a process-based demographic model (BiomeE), and forecast shrub encroachment across the US Great Plains under future climate scenarios (Weng *et al. in review*). An ecohydrology project funded by NSF-EAR (Sullivan & Nippert) assesses how woody-encroachment enhances rooting depth, water and carbon transport, water age and the potential for weathering at depth using integrated field and modeling approaches. Lastly, with funding from the NSF-LTREB program (Baer, Blair & Collins), we will continue to test the effects of soil heterogeneity on plant diversity following 20 yrs of restored prairie development (Baer *et al.* 2020) and use the 25-yr dataset spanning two droughts to enable us to assess the role of heterogeneity on resilience of restored grassland.

Broader Impacts

VIII: EDUCATION AND OUTREACH ACTIVITIES

K-12 Education – The Konza Environmental Education Program (KEEP) brings local and regional K-12 children to the tallgrass prairie to observe and gather data, both directly and virtually. Collaborations between KNZ scientists and KEEP staff have produced activities that mirror site science, allowing students to emulate KNZ research, and collect and analyze meaningful data. Student participants in KEEP follow Schoolyard LTER (SLTER) protocols and study diverse topics, including grasshopper population dynamics, plant responses to fire, geomorphology of stream channels, stream invertebrates, and plant diversity changes. Students enter data in an online database that integrates with other classes. Visualization tools allow students to see data trends and patterns to understand the power of long-term research. Regional teachers who are unable to visit KPBS can still use KNZ SLTER protocols to add data from their local grasslands to our database. KEEP collaborates with the regional school districts, Kansas Association for Conservation and Environmental Education, the Flint Hills Discovery Center, and the Boys and Girls Club to promote discovery and grassland heritage among school-aged children.

During LTER VIII, we will develop additional SLTER activities including case studies with KNZ bison and grasshopper data. These case studies will guide students through SLTER datasets to teach how climate variability and change can affect bison weight and grasshopper diversity over time. To increase accessibility, we will put these activities and datasets online. We will offer local Summer Teachers' Workshops and protocols for adoption at remote sites, allowing us to curate and provide a broader online database. KNZ has produced a children's book, *The Autumn Calf* (SLTER Children's Book Series), and will train teachers to use it in the classroom. The book introduces children to the prairie, to science, and to concepts related to themes in the story, such as migration, phenology, and animal behavior. We will develop new curricula for educators to use with the book to introduce concepts in ecology. This curriculum will be available on our website and will be aligned with Next Generation Science Standards.

Undergraduate, Graduate, Postdoctoral Education – KNZ scientists are committed to providing high quality opportunities for training a diverse cohort of undergraduate and graduate students. We employ approximately 50 undergraduates annually to assist with research and data collection. An additional 200-300 undergraduates per year utilize KPBS as an outdoor classroom for field trips, course activities, and research tours. A site-based REU program from 2014-2017 hosted 21 students, with an additional 12 REU students sponsored by KNZ LTER VII. Of these 33 REU students, 51% were female, and 57% were under-represented ethnicities. Testimonials from REU students were positive, with details hosted on our website. KNZ also provides stipends and training for numerous graduate students (currently KNZ graduate students are > 60% female). During LTER VII, 53 theses and dissertations from 9 institutions were completed. KNZ will continue to provide graduate stipends and other forms of support (vehicle use, site access, analytical laboratory use, travel to professional meetings) for 15-20 students annually. KNZ has a strong history of mentoring and training graduate students. The majority of our former PhD students (>90%) obtain postdoctoral fellowships or become faculty at other institutions. Of this group, many continue to participate in KNZ studies and, and frequently lead new KNZ research activities.

Increasing Diversity and Inclusion – KNZ investigators are committed to fostering diverse scientific communities and providing inclusive pathways to success for individuals of gender, racial, and ethnic groups historically underrepresented in science. We capitalize on K-State resources, including the McNair and Developing Scholars programs, to provide research opportunities for underrepresented undergraduates. We have begun participating in the NSF-funded Louis Stokes Alliance for Minority Participation at K-State, hosting students from Research Immersion Pathways to STEM program (first generation, Hispanic, community college undergraduates). Each summer we expose undergraduates from the Haskell Environmental Research Studies (HERS) program to KNZ research and experiments, drawing linkages between the impacts of climate change and issues important to indigenous communities. During LTER VIII, we will expand our interactions with Haskell Indian Nations University and HERS to develop programs of interest to American Indian/Alaska native communities and improve research opportunities for Haskell students. We use the K-State Office for the Advancement of Women in Science and Engineering to foster development of female collaborators. As detailed in the *Project Management Plan*, female faculty investigators comprise the majority within our Executive Committee, Scientific Steering Committee, and KNZ staff. Gender balance within KNZ leadership improves representation of multiple perspectives in our decision-making process, improves satisfaction of participants, and promotes sustainable development of our program.

Community Outreach and Engagement – KNZ scientists, students, and trained volunteer docents provide research tours for the public, land managers, conservationists, and policy-makers. In the past 6 years, > 50 grassland-related professional groups totaling > 3,000 individuals visited KPBS for information and training. KNZ will continue to host conservation meetings such as Grasslands of the World (2015), Grassland Restoration workshop (2017), and American Society of Mammalogy (2018).

Linking Science and Art – During LTER VII, KNZ and KPBS cultivated new opportunities for tallgrass prairie outreach through art. We collaborated with the Beach Museum of Art to establish the *Prairie Studies Initiative*. KPBS hosts numerous artists annually. A featured artist, Erin Wiersma, has artwork at the Robischon Gallery (Denver, CO), Galerie Fenna Wehlau (Munich, Germany), Salina Art Center (KS), and A.I.R. Gallery (Brooklyn, NY). Wiersma participates in prescribed fires and uses char from fires to create large-scale drawings. Her process melds personal experiences on the landscape with the essence of the prairie fires and site characteristics. For further engagement, co-I Dr. Alice Boyle developed a musical performance series (with Robert Rosenberg) relevant to grasslands, birds, climatic variability, and the experiences of the humans who share the environment. Finally, KNZ hosted a “Cross-Disciplinary Workshop and Engagement: An Art-Science Workshop” in 2016 with > 40 attendees. We will continue these activities and develop new art-science interactions during LTER VIII.

Science Communication – KNZ scientists and students regularly engage in numerous science outreach and communication activities including the Science Communication Fellowship (SCF) with the Sunset Zoo in Manhattan, KS. The SCF program supports a network of certified researchers, professionals, and students working to increase the community’s understanding and exposure to regional research. KNZ investigators also participate in the Kansas Science Communications Initiative, which trains scientists to improve communication to the public. KNZ graduate students lead the *Science Snapshots* blog used to summarize the objectives and outcomes of one another's research for public dissemination.

Grassland Conservation and Restoration – Tallgrass prairies in the Flints Hills support a >$8B grazing economy based on >1 million cattle annually, constituting one of the largest sectors of state revenue. We work with *The Nature Conservancy* of KS and K-State Extension to translate research results into best-practices and conservation recommendations, including timing and frequency of prescribed burning to maintain cattle performance while optimizing conservation goals (e.g., patch-burn grazing), such as grassland bird and plant diversity and carbon storage. KNZ science provides best practices for recovery /remediation of abandoned agricultural lands and invasive species management, as well as contributing to smoke management plans developed for the region, in collaboration with the Region 7 EPA, Natural Resources Conservation Service, Kansas Farm Bureau, and the Kansas Livestock Association.

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Facilities, Equipment and Other Resources

The 3,487-ha Konza Prairie Biological Station (KPBS), located in the Flint Hills of north-east NE Kansas, is the core research site for the KNZ program. In addition to the watershed-level fire and grazing treatments, agricultural fields, restored prairie, stream network and weirs, KPBS includes several buildings in the headquarters area that support LTER research. The on-site Ecology Laboratory (2,400 ft^2) includes (1) a wet/dry lab with sinks, fume hood, refrigerators, balances, etc., (2) two large multi-purpose work rooms with bench space and sinks for processing samples, drying ovens, refrigerators and freezers, and equipment storage, and (3) and a large researchers' shop equipped with a variety of tools and field supplies. Other station buildings include a fire station and maintenance building, a large storage building for equipment, and a residence occupied by the KPBS site foreman year round. The 4,650-ft^2 Hulbert Center houses a library/conference room, administrative offices, classroom and teaching laboratory (used primarily for K-12 activities), reference herbarium and animal collections, and a kitchen and dormitory-style housing for 15 visitors. Two small guest cottages (each with 2-bedrooms living room, bath, kitchen, and laundry facilities), can accommodate up to five people/cottage. A larger cottage, built in 2012, can accommodate up to 12 guests, expanding the capacity of on-site accommodations to 37 visiting researchers.

During LTER VI, the historic limestone barn at the KPBS headquarters was transformed into a multipurpose meeting facility for on-site conferences, workshops, and educational programs. The barn was renovated in 2008 and includes the Cortelyou Lecture Hall (1,750 square feet) with a seating capacity of ~100 persons fully equipped with A/V equipment and wireless internet. An additional large multi-purpose room (1,850 square feet) is designed as flexible space for varied uses including additional meeting space, workshops, scientific posters and other research displays, social gatherings, and education programs for large groups. During LTER VII, the meeting capabilities within the barn were upgraded to include better internet connectivity, and a dedicated PC for presentations.

All lab and office buildings have T1 Internet connectivity to the KSU campus. In addition, we have installed a wireless link to KPBS from campus with multiple wireless access points (802.11abg) that provide coverage to >60% of the 3,487-ha site for real-time uploads of field data from sensors or other inputs. Current users include: KNZ LTER (sensor networks in several locations, meteorological stations, eddy flux towers, stream discharge loggers), USGS, University of Kansas, Colorado State University, and KPBS (visiting scientists lodging). Network upgrades to increase both coverage and throughput are possible.

Other LTER infrastructure maintained by KPBS includes the outside perimeter fence (29.8 km), the interior bison management area enclosed by 16.4 km of "New Zealand" fence, 98 small (25-m^2) grazing exclosures, 11.7 km of fence for cattle research, 26.4 km of access roads and 61 km of fireguards separating the experimental watershed units. KPBS maintains several general-purpose vehicles on-site, as well as specialized equipment (tractors, fire trucks, mowers, soil augers, etc.). KPBS makes available staff and equipment to assist with KNZ research activities, including mowing fireguards, installing equipment, soil coring, etc. KPBS and KNZ staff coordinate the fire management plan and implementation of prescribed burning of watersheds and experimental plots, and the management of bison and cattle herds for KNZ grazing treatments. The headquarters area include a corral and handling facilities for managing the bison herd (hydraulic chute, electronic scales, etc.), which is essential for LTER grazing studies. Using funding support from a NSF FSML grant in 2018, we upgraded the bison handling facilities to improve bison handling safety and ease of access. This FSML grant also improved site-access points within the broader site and upgraded animal scales that record changes in animal biomass. Other field equipment and instrumentation at the site includes the main KNZ weather station, a network of 11 rain gauges, three eddy flux towers for quantifying ecosystem-level C and water vapor flux, four weirs and associated stream gauging equipment (updated in 2012 to Sutron Constant Flow Accubar® bubble gages and recorders with wireless connectivity), 46 wells for measuring groundwater levels and chemistry, numerous TDR probes, neutron access tubes and tension lysimeters for soil water measurements. Related equipment co-supported by other programs includes a USGS stream monitoring station, a NASA CIMEL Sun Photometer, 2 seismometers (USGS), an aerosol and ozone monitoring facility (CASTNet), and a NOAA Climate Reference Network (CRN) weather station; these facilities add significantly to data for LTER research and education programs, and for regional and cross-site studies. The KPBS also hosts a core aquatic and terrestrial NEON site, as well as a satellite terrestrial NEON site in agricultural lands near the site entrance.

In addition to facilities at KPBS, a wide-range of modern laboratory facilities are available on the nearby KSU campus approximately 15 km from KPBS (*e.g.,* Analytical Chemistry Labs, Stable Isotope Lab, Center for Ecological Genomics, Core Sequencing and Genotyping Facility, Lipodomics Center, Gene Expression and Microarray Facility, a BioSafety Level 3 Facility for invasive species and infectious disease studies, etc.). The majority of core LTER laboratory space and analytical equipment are located in Bushnell Hall (Biology), including space and equipment for preparing plant, soil and water samples for analysis (drying ovens, grinders, shaker tables, block digestors, vacuum filtration systems). Bushnell Hall also houses an extensive collection of prairie plant specimens in the KSU Herbarium, and these specimens are now electronically databased and georeferenced. Some specific equipment and facilities are located within other Departments (Agronomy, Biological and Agricultural Engineering, Plant Pathology, Geography), reflecting the interdisciplinary nature of our research. Some of the major analytical equipment available for LTER research includes: 2 Alpkem autoanalyzers (FlowSolution IV) for liquid samples, Carlo-Erba 1500 automated C/N analyzer for solid samples, Shimadzu TOC 500 analyzer for dissolved C, a Hitachi U2900 automated dual-beam spectrophotometer, several gas chromatographs with electron capture, flame ionization and thermal conductivity detectors, a Nikon compound microscope with epifluoresence and video imaging capabilities, 4 LiCor 6400 Portable Photosynthetic Systems, 2 LiCor 8100 systems dedicated for soil CO_2 flux measurements, a LiCor 1600 null-balance porometer for stomatal conductance, and 3 pressure chambers (PMS model 1000) for measuring plant water potential, 4 Tektronix cable testers (model 1502B) coupled to Campbell CR10 data loggers for TDR soil moisture measurements, 2 Troxler (model 3221) neutron probe gauges for soil moisture determinations, a back-pack mounted minirhizotron (Bartz Technology Co) camera system, and Trimble GPS units. Eight multi-parameter sonds (YSI 6000) are used for monitoring oxygen and temperature in 3 watersheds. Cold storage facilities for holding samples are available, as are sample preparation rooms for drying and grinding plant and soil samples. Climate controlled greenhouse space is available on the KSU campus. In addition, other “typical” laboratory equipment (balances, microscopes, etc.) is available in individual investigator laboratories.

Presently, KNZ manages 6 pickup trucks (ranging in model year from 1994-2015), a 12-passenger van, and several smaller vehicles to move student researchers and materials between campus and the field station, and for work on site. Individual PI's at KSU also maintain their own field vehicles for transport to and from KPBS.

Other KSU Facilities

KNZ PI Nippert is the director of the Stable Isotope Mass Spectrometry Laboratory (SIMSL) in the Division of Biology at Kansas State University. The laboratory is dedicated to the stable isotopic (‰) and elemental (%) analysis of carbon (C), nitrogen (N), and oxygen (O) in organic and inorganic phases (solids, liquids and gases). SIMSL is a hands-on teaching facility for the students (undergraduate and graduate) at Kansas State University, and a regional research facility for stable isotope users. The lab supports research in a multitude of natural science disciplines, including ecology, soil science, agronomy, and geology. SIMSL operates an Elementar VISION Isotope Ratio Mass Spectrometer with a Pyro Cube elemental analyzer. Additionally, SIMSL operates a Picarro isotopic water analyzer and a Picarro isotopic CO_2 analyzer. SIMSL is equipped to process samples using Wiley mills, ball mills, small-sample amalgamators, soxhlet, and has a vacuum extraction line to cryogenically extract water from plant and soil samples.

The KSU GIS Spatial Analytical Laboratory (GISSAL) was established in 1990 as a multidisciplinary center supporting spatial research, education, and outreach activities at Kansas State University. GISSAL was recognized as a National Center of Digitizing Excellence by the USDA Natural Resource Conservation Service and key contributor to the 2005 ESRI Special Achievement in GIS Award for Agriculture awarded to KSU. GISSAL combines faculty expertise and trained graduate and undergraduate student technicians with advanced geospatial technology and sophisticated spatial analysis capabilities. GISSAL offers a modern computing infrastructure, access to state-of-the-art data visualization tools, and the most powerful GIS, satellite remote sensing, digital mapping, database, and statistical analysis software packages. Although primarily a research facility, GISSAL also offers contract services including GIS database design and construction, digital cartographic support and production, web-servable maps, distributed geographic information services, and customized GIS workshops and software training.

Computer Software and Hardware

Most laboratories, all PI offices, and KPBS buildings have personal computers, linked to a local area network managed by the KNZ LTER program, with support via a contractual arrangement with the KSU Physics Computer Support Center (PCSC). Details on the servers, database, data storage, wireless connectivity, and available software are provided in the Data Management Plan (see Table 1 therein).

KSU Institutional Support

Kansas State University has a long history of providing support for the KNZ LTER program, which will continue during the LTER VIII funding cycle. KSU will provide computer server and network support through a partnership between the KNZ LTER program and the KSU Physics Computer Support Center (PCSC), where KNZ network servers are housed (specific details provided in the Data Management Plan). KSU will provide support for operation of the Environmental Chemistry Laboratory in Bushnell Hall, which is used for LTER water sample analyses. KSU is committed to providing support for large equipment needed during LTER VIII, such as vehicle replacement or -80 ºC freezers for sample archival. KSU is committed to supporting undergraduate research assistants to assist with core data collection and the maintenance of the experimental treatments at KNZ. Finally, KSU will also provide support in the form of available assistantships for graduate students conducting KNZ research. These assistantships include stipend plus tuition for year-round support.

'As instructed in the solicitation, this information is being submitted as Other Supplementary Documentation’

KNZ Project Management Plan

The success of the KNZ program is built on shared intellectual leadership, continuity of programmatic vision, and providing substantial advisory roles and mentoring for the next generation of PIs. Although participants and organizational themes have changed over time, a model of shared intellectual input, distributed leadership, and group decision-making has served KNZ well for nearly 40 years. We strive to be inclusive of all project participants, to offer junior members leadership roles on papers and in governance, and to freely share our data among researchers (within and outside of the KNZ group). We are committed to providing a safe, welcoming, diverse, and supportive environment for research.

Our governance and organizational structure (Table 1) is built around the current roster of PIs and the major themes of KNZ research over time. Jesse Nippert will serve as PI-of-record and primary KNZ LTER point-of-contact at the local (University), LTER Network, and NSF levels. The PI is responsible for overall scientific leadership, coordination of KNZ activities, administration of KNZ staff, fiscal oversight, timely reporting to NSF, and communication with the LTER Network Office (LNO). The PI works closely with an Executive Committee comprised of the four signatory co-PIs to manage the project. The Executive Committee provides input on decisions that require significant LTER resources (*e.g.,* support for new investigators, budget issues, etc.), decisions that could significantly affect KNZ research groups, and provides the first response to requests from the LNO or from NSF. For decisions requiring broader input and coordination, we have a KNZ Scientific Steering Committee, consisting of the Executive Committee plus other key senior personnel. Given the multi-disciplinary nature of the KNZ program, the Steering Committee is comprised by scientists with a range of experiences, perspectives, and career stages that share a common commitment to maintaining the quality of the program. The Steering Committee is tasked with setting the scientific direction of the KNZ research program and meets for strategic planning at our annual KNZ workshop and remotely as needed during the year. We cluster researchers into Research Groups, based on broad themes of inquiry, typically with co-leaders for each group, though we realize there are not hard and fast intellectual boundaries between these groups (Table 1). Group leaders coordinate activities and projects within thematic areas, provide timely communication of new projects, respond to specific requests for information or collaboration, and provide advice to the PI regarding allocation of LTER resources. KNZ staff members are evaluated annually by an LTER Personnel Committee comprised of KNZ co-PIs and Senior Investigators, with the intention of defining individual responsibilities, evaluating annual performance, setting goals for the upcoming year, receiving input on project management, and input on staff relations. The Personnel Committee reports to the PI, who makes decisions regarding reappointment and any merit-based salary increases, and considers other staff requests. Nippert also holds monthly staff meetings for general planning, to discuss new projects, and to promote camaraderie amongst our staff.

In addition to fostering participation in KNZ project management, our administrative model attempts to maximize involvement of KNZ investigators in LNO activities. For annual LNO Science Council meetings, Nippert selects accompanying KNZ investigators based on the theme of each meeting. We use KNZ resources to support additional investigator attendance at the LTER All-Scientist Meeting, especially for graduate students, postdocs, and junior faculty. Finally, we strongly encourage individual participation in other LTER committees, working groups, and activities. KNZ scientists have been well-represented in the LTER synthesis working groups over the past 6 years, contributing our site data and perspectives to broad ecological syntheses.

We promote scientific and programmatic collaboration among KNZ investigators in multiple ways. All investigators (at KSU and at other campuses) are included on appropriate e-mail lists for distribution of information and requests. For example, Nippert currently serves on the LTER Science Council Executive Board. Information from these meetings and communication from NSF and the LNO are routinely forwarded to the KNZ Executive or Scientific Steering Committees or, if appropriate, to all KNZ investigators. In addition, a Konza listserv (Konza-l) is used to broadcast announcements and disseminate information to all researchers. KNZ investigators regularly interact using variety of meeting types. During the academic year, we hold bi-weekly meetings for all KNZ scientists and graduate students, with off-campus participants joining by teleconference. The meeting format varies, but includes research presentations, planning for new projects, syntheses, and group discussion of recent LNO requests (e.g., LTER decadal review). We host an annual KNZ Workshop (May, 2020 will be our *29th meeting!*). Research presentations (oral and poster) are contributed by faculty, post-docs, graduate and undergraduate students. The meeting fosters informal interactions during the day, with a planning meeting for the Scientific Steering Committee and other senior personnel. This meeting includes nearly all Konza investigators, including off-campus researchers, local scientists, students, staff, K12 educators, and docents. For the last several years, KNZ has hosted 'Winter Synthesis Meetings' for interested students, staff and faculty investigators. These synthesis meetings include data integration/analysis, discussion of results, and future planning on a topical (e.g., data from nutrient or precipitation manipulation experiments) subject relevant to our program.

Originally, KNZ investigators came predominantly from the KSU Division of Biology. However, the availability of KNZ resources and data have been invaluable in attracting new investigators, and over the last several decades our research program has grown to include multiple departments at KSU and at other universities. In LTER VIII, we will continue expanding institutional and scientific diversity and encourage involvement of additional investigators through: on-site logistical support, opportunities for graduate students, dissemination of information regarding LTER supplements to new researchers, and providing “seed money” to new researchers when possible for involvement during the course of LTER VIII. At present, LTER VIII includes new faculty members from KSU Biology (Andrew Hope, Allison Louthan, Zak Ratajczak), as well as from other departments at KSU including Geography (Abby Langston), Bio/Ag Engineering (Trisha Moore), Agronomy (Eduardo Santos and Chuck Rice), Animal Science (KC Olson), and Geology (Matt Kirk). Many non-KSU faculty have remained engaged in the KNZ program over several funding cycles, and continue to provide fundamental input including Sara Baer and Nate Brunsell (Univ. of Kansas), Melinda Smith and Alan Knapp (Colorado State), and Gail Wilson (Oklahoma State). We have retained participation from former postdocs (now faculty) including Kevin Wilcox (Wyoming), Meghan Avolio (Johns Hopkins), Sally Koerner (UNC-Greensboro), and Kim Komatsu (Smithsonian), and we continue to recruit new faculty to the program (Pam Sullivan - Oregon State).

KNZ successfully implemented the original LTER Program goal of building on a stable funding base managed such that the turnover of individual investigators and/or completion of scientific careers does not compromise the continuity of established experiments, and long-term, site-based data collection (Callahan 1984). KSU faculty led by G. Richard Marzolf initiated **LTER I** (1981-1986) with a site-based fire and grazing experiment designed by Lloyd Hulbert. KNZ expanded greatly during **LTER II** (1986-1990), under the leadership of Don Kaufman and Tim Seastedt (co-PIs during LTER I) to include the bison grazing treatments. Following Seastedt’s departure in 1991, Alan Knapp and John Briggs provided leadership and administration for **LTER III** (1991-1996), with co-PIs David Hartnett and Kaufman in advisory roles. Leadership during **LTER IV** (1996-2002) was provided by Knapp and John Blair, with co-PIs Hartnett, Kaufman, Walter Dodds and Loretta Johnson. Blair assumed administrative responsibilities at the midpoint of LTER IV, and served as lead PI of **LTER V**, with Knapp, Briggs, Hartnett, and Johnson as Co-PIs. Blair led **LTER VI** with Dodds, Anthony Joern, Hartnett and Jesse Nippert as co-PIs. Briggs re-joined the KSU faculty in 2008 as Professor and Director of the Konza Prairie Biological Station (KPBS), a new position created to support interactions of the KNZ program with KPBS. **LTER VII** was led by Blair, and included Sara Baer (SIU), Dodds, Joern, and Nippert as co-PIs. Baer was the first non-KSU faculty member to serve as co-PI. During LTER VII, Nippert stepped into the role of KNZ PI following a successful mid-term site review. Blair succeeded Briggs as KPBS Director, and will continue involvement in the KNZ program, while Briggs, Hartnett, Joern, and Kaufman have retired.

KNZ LTER VIII includes planned leadership changes, while maintaining continuity of the program and involvement of several key long-term investigators. Nippert will serve as the PI, with Sara Baer (now at KU), Keith Gido (KSU), Melinda Smith (CSU), and Lydia Zeglin (KSU) as co-PIs. Gido and Smith have played key roles in the KNZ program over the past two decades, and Zeglin has provided program leadership and new perspectives since her arrival in 2014. Former signatory co-PIs Blair and Dodds will continue supporting and guiding the KNZ program. Maintaining a diverse and inclusive culture is a priority for the KNZ program, and leadership within both the Executive Committee and Scientific Steering Committee is comprised by a majority of female scientists for LTER VIII.

We do not anticipate changes in program leadership over this next funding cycle. However, we will continue to integrate younger, incoming faculty members and mentor them for potential future leadership roles, as was done for both Nippert (LTER VI) and Zeglin (LTER VII). KSU recently hired two grassland ecologists (Louthan and Ratajczak) to fill positions opened with recent retirements, and will provide opportunities for increased KNZ leadership and responsibilities in a logical and timely fashion. Maintaining an open and welcoming leadership group has the advantage of broadening input into overall management decisions by including researchers at different career stages and research expertise, preparing for smooth succession of leadership for the future, and expanding diversity within the KNZ LTER Executive and Scientific Steering Committees.

Table 1: Organizational structure of the Konza Prairie LTER VIII Program

Executive Committee/PIs

S. Baer, K. Gido, J. Nippert, M. Smith, L. Zeglin

Scientific Steering Committee (in addition to PIs)

M. Avolio, J. Blair, W. Dodds, J. Haukos, A. Knapp, S. Koerner, K. Komatsu, A. Louthan, Z. Ratajczak, K. Wilcox, Y. Xia

Konza LTER Staff

Yang Xia (Information Manager); Jennifer Rhodes (Admin. Asst); Amanda Kuhl (Field Sampling Coordinator); Courtney Tobler (Analytical Chemist); Jeff Taylor (Plant Sampling and Bison Management); Mark Sandwick (Field Experiments); Pam Blackmore (GIS Specialist); Jill Haukos (KEEP Director & Schoolyard LTER Coordinator)

Konza LTER Research groups

Primary affiliations are indicated, but most researchers participate in several groups. Bold font indicates group leaders/co-leaders.

Fire/ grazing studies	**Woody plant expansion**	**Climate change**	**Biogeo-chemistry**	**Restoration**	**Synthesis**
M. Avolio	J. Blair	M. Avolio	M. Avolio	**S. Baer**	**M. Avolio**
J. Blair	N. Brunsell	J. Blair	**J. Blair**	J. Blair	S. Baer
A. Boyle	W. Dodds	N. Brunsell	**W. Dodds**	S. Collins	J. Blair
S. Collins	A. Hope	W. Dodds	A. Jumpponen	K. Gido	S. Collins
W. Dodds	**J. Nippert**	K. Gido	M. Kirk	J. Nippert	W. Dodds
K. Gido	E. Santos	**A. Knapp**	A. Langston	G. Wilson	K. Gido
A. Hope	**Z. Ratajczak**	S. Koerner	C. Rice		T. Hefley
E. Horne	L. Zeglin	K. Komatsu	M. Smith		A. Knapp
M. Kirk		A. Langston	P. Sullivan		S. Koerner
A. Knapp		T. Moore	**L. Zeglin**		**K. Komatsu**
S. Koerner		C. Rice			A. Louthan
K. Komatsu		**M. Smith**		**Education & Outreach**	J. Nippert
A. Louthan		P. Sullivan			Z. Ratajczak
J. Nippert		**K. Wilcox**		J. Blair	M. Smith
E. Santos		G. Wilson		W. Dodds	**Y. Xia**
M. Smith		L. Zeglin		**J. Haukos**	K. Wilcox
E. Welti				E. Horne	**L. Zeglin**
G. Wilson				J. Nippert	
K. Wilcox				L. Zeglin	
L. Zeglin					

Konza LTER Data Management Plan

The goal of the KNZ Information Management System (IMS) is to facilitate research and scientific discovery at the Konza Prairie Biological Station and beyond by delivering high quality data and metadata. The KNZ IMS conforms to LTER best practices, and provides the infrastructure for the curation, protection, access, and analysis of data collected for core LTER monitoring and associated experimental studies.

LTER VII Accomplishments - A major IMS accomplishment during KNZ LTER VII was the implementation, redesign, and launch of the new KNZ website based on the Drupal Ecological Information Management System (DEIMS, Drupal 7) (http://lter.konza.ksu.edu/). The new website represents a significant step toward our goal of integration of all data products in a common IM framework. The DEIMS EML-export system automatically generates PASTA-compliant, attribute-level EML files for each KNZ dataset. This system provides a more user-friendly and reliable website, as well as improved ability to update web content as needed.

During KNZ LTER VII, we organized and integrated long-term data, standardized attribute codes, keywords and units with KNZ and LTER Network standards where applicable, and provided more detailed metadata. We modified scripts to produce EML that passes new PASTA congruence checks. We updated the KNZ intellectual rights statement for use with the Creative Commons license agreements (http://lter.konza.ksu.edu/data/information-management/konza-prairie-lter-data-access-policy). We also expanded the KNZ data catalog with new LTER datasets and associated metadata (24 new projects added during the last funding cycle).

We created a LAMP Ubuntu server on two virtual machines to support the production servers for the KNZ website and to enhance technical capabilities and provide access to advanced features. We replaced our aging operating system (2012 R2) with a new Windows server (2016 Hyper-V) cluster. These infrastructure upgrades included the domain controller, switches, storage, and 14 virtual machines, as well as software upgrades on all physical servers, HyperV modes, domain controllers, and management machines.

Response to LTER mid-term review - We received positive and constructive feedback on the KNZ IMS in our mid-term review. In response, we revisited all datasets to ensure that they are clear, correct and consistent with LTER metadata standards. To increase the visibility of KNZ broader impacts, we were encouraged to develop an *Outreach* section - (http://lter.konza.ksu.edu/konza-lter-outreach), along with statements on KNZ policies regarding diversity, inclusivity, and non-harassment (http://lter.konza.ksu.edu/home/diversity-statement). We also added a section showcasing our REU students and their projects, as well as a photo repository available for KNZ investigators and the public organized by albums and searchable by photographer and keywords.

IM Resources - The KNZ IMS includes people, hardware, and software with the mission of storing, managing and delivering scientific information that facilitates interdisciplinary research and scientific discovery. KNZ personnel include Yang Xia (full time Information Manager with responsibilities for data management, website/database design, implementation, and oversight of KNZ LTER computer network activities), Larry McFeeters (contracted IT support from KSU, with responsibilities for webserver/system administration, IT Security, and desktop support); Jennifer Rhodes (administrative assistant), and additional part-time student employees (for data collection, entry, and error checking). In summer of 2019, KNZ welcomed Pam Blackmore (GIS Specialist) to the data management team. Pam oversees GIS data management and works closely with Yang and Jennifer to integrate GIS data within the KNZ IMS.

Hardware and Software: The KNZ IMS includes a local area network that supports IM access, data entry workstations, over 90 KNZ user accounts, shared software, and storage. This network is for KNZ use and is separate from other KSU campus networks. All KNZ servers are managed by the KSU Physics Computer Support Center (PCSC). Contractual support with PCSC frees the IM from maintaining server hardware and software, and allows greater time to focus on managing and serving data and metadata to support local, network, and other research and education activities. Details on hardware and software are presented in Table 1.

<u>Website:</u> The KNZ website provides data and content management, metadata with robust search options, and data access for research and education. All web and database content, including spatial data (GIS datasets and KML files) were migrated into a MySQL database, based on Drupal 7 - DEIMS (Version 2) and are served on a new website. The website provides access to all KNZ data, publications, research activities, and products, including 135 projects. All online data are searchable by KNZ data categories, LTER controlled vocabulary keywords, LTER core areas, KNZ watersheds, and data owner. We maintain an updated list of all KNZ LTER-supported/related publications, with standardized formats. Currently, the KNZ IMS hosts 1889 publications, searchable by keyword, author, year, and publication type. Website usage is tracked by Google Analytics and indicates approximately 1500 visits and 4000 page views per month in the past year (77% new visitors).

Policies – The KNZ Data Access Policy is compliant with LTER IMC LTER Executive Committee guidelines. It adheres to the LTER Network Data Access Policy and NSF Proposal/ Award Policies. KNZ IMS is dedicated to making all long-term datasets and key short-term data available on the website and in the EDI Data Portal within two years of data collection, processing, and completion of appropriate quality control procedures.

Most KNZ datasets are Type I - collected using KNZ funds and released to the general public within 2 years of data collection. A few Type I datasets require a longer time for sorting, processing, and QA/QC (e.g., primary productivity ~ PAB01). Upon finishing quality control, Type I datasets are archived in the KNZ and EDI systems. Type II datasets are from graduate student research, short-term studies, one time surveys, or projects supported by other funding. These datasets are made available to the information manager/PI's, and may be placed online within 2 years of completing quality control, at the discretion of the IM/PIs. Data not supported by LTER funds are placed online only if mutually agreed upon by the investigators and the IM. All KNZ researchers have an obligation to submit all LTER-funded data to the KNZ database and to publish those data in a timely fashion. We also recognize that KNZ investigators should have a reasonable opportunity for first use of data they have collected.

The KNZ LTER data and metadata are released using a Creative Commons CC-BY license. We ask authors of all publications, reports and proposals who use any data from KNZ to provide proper attribution. To aid in this regard, we provide suggested text for KNZ attribution in the Data Access Policy of our website.

KNZ LTER Supporting the Data Life Cycle - The KNZ IM team addresses all eight components of the data life cycle for managing and preserving data for use and reuse as described by DataONE's best practices (https://www.dataone.org/data-life-cycle).

<u>Data Plan, Collection, Processing and Validation</u> - The KNZ IM team collaborates with scientists and students prior to the initiation of new research projects, and assists with planning data collection and the data structure design. Data are collected from a wide range of ongoing long-term experimental studies and monitoring programs, ranging from plot-level data on plants and soils, to high frequency instrument data from meteorological stations and eddy covariance flux towers. The IM leads an annual workshop for graduate students introducing the KNZ IMS and providing best practices for data structure, LTER metadata standards, and metadata creation and submission. The IM participates in all KNZ activities, including biweekly meetings, synthesis workshops, and the annual meeting.

Spatial data from KPBS are stored locally in a file geodatabase (GDB) format using Esri ArcGIS software. These data are available for download through our website and spatial data portal in zipped Shapefile (SHP), Keyhole Markup Language (KML), or GeoTIFF (TIF) formats. If required, some large images, such as satellite imagery, can be downloaded from our web server through arrangement with the IM. We continue to increase our spatial data offerings, including historic data by digitizing and rectifying a series of historic aerial photographs, long-term, and current plot locations for research activities on site. Using high-resolution GPS units, we georeferenced over 95% of sampling locations related to LTER dataset collections and are continuing to add other research locations as new projects are initiated. Metadata for each of these spatial data files is compliant with the Content Standard for Digital Geospatial Metadata (CSDGM) recommended by the Federal Geographic Data Committee (FGDC).

For field data that are hand-collected, we initiated procedures to electronically log samples and follow their processing. For example, water samples are logged in a tracking database after collection, and include any comments associated with those samples. The samples are then subsampled and filtered, and labeled vials are frozen and stored in our analytical labs. Control sheets and procedures are then used to ensure data and sample flow and accounting.

Other data are collected electronically in the field. For example, plant composition data are collected on a tablet equipped with Filemaker software. A custom database allows the user to select only valid plot designations, species names, and cover values, reducing both transcription errors and processing time. As another example, bison weight data are recorded with an electronic scale and EID reader and automatically sent to a database, reducing errors.

Some KNZ data are derived directly from field-based electronic sensors (e.g. weather stations, stream gauges). Processing routines are managed with custom SAS software programs which execute appropriate range and error checks, create flags and alarms where necessary, and perform the necessary conversions and reformats required for input into the IMS.

A few historical data sets have not yet been incorporated into our online database, but are available upon request. Non-digital data (e.g., historic photos, field notes, etc.) are archived along with all original field notes and data. When requested, we can provide digital scans (.pdf) to complement MySQL and ASCII version of the data for every available dataset. Our intent was to make these scans internally available, to enable cross-checking data or viewing original datasheets without visiting the physical archives.

Data quality assurance and quality control are essential for data integrity and management. Researchers, assistants and students who collect the data are responsible for their own data entry, quality control, documentation and analysis, with guidance by the IM by request. The KNZ IM offers advice and expertise in data collection, storage, and archival issues where needed, particularly as new studies begin. A key investigator is assigned responsibility for each dataset. The IM encourages researchers to submit their data as comma delimited files along with a detailed metadata file. The error-checked dataset is then returned to the responsible investigator-of-record, who provides a final data check and approval before the data are placed on the internal data server. An additional automatic error check, including a data validation step using preset thresholds to limit data to an acceptable range are conducted.

Once data quality assurance and quality control steps are completed, the IM is notified that the data are ready to archive. The IM then uses a data analysis tool (Excel, SAS, SQL, R, OpenRefine, Tableau) as an additional quality control to double check the data and metadata, and communicate with the data owner to make sure all data conform to LTER data and metadata formats, LTER standards, and best practices. Afterwards, the IM loads data into existing data tables or creates a new project data table in the MySQL database. This workflow for data processing (from field data collection through entry, QA/QC, and query) supports prompt data entry and updates. During LTER VIII, we will continue to improve and build on these workflows to enhance the efficiency of the KNZ program through time.

Data Documentation and Curation - The KNZ data catalog (metadata), methods manual (techniques), and instructions for how to submit data/metadata are available online. Metadata are submitted to the IM as MS Excel or text files by KNZ researchers. KNZ EML metadata incorporates best practices including keywords drawn from the LTER Controlled Vocabulary, assigned keywords for the LTER Core Areas, unit descriptions that conform to the LTER Unit Registry, and newly added ORCIDs in the EML for identifying researchers. KNZ structured metadata also allows linking datasets, publications and personnel with better search capabilities, compatible with the LTER Network Information System.

Data Access and Analysis - KNZ makes data available in accordance with the LTER Data Access Policy. All KNZ datasets can be accessed via the KNZ Data Archive and the EDI data repository and discovered via DataONE. There are 350 online datasets from 135 projects available using an interactive search interface, including many long-term datasets >10 years (12% of all data packages). Of the data packages, 37 are related to the “Primary Production” core area, 11 to the “Organic Matter” core area, 31 to the “Inorganic Nutrients” core area, 74 to the “Disturbance” core area, and 64 to the “Population” core area. In addition, we have many data packages that span multiple core areas, and GIS (20) and Climate/Hydro data (24) packages not specifically linked to a specific core area.

The KNZ website allows user access to all research data with DOI identifiers. With the new ‘Data Explorer’ feature, users can query data tables and explore the data before downloading. To optimize data discovery, we improved a number of filters for data search, including capability to search by LTER core area, the lead investigator, location, duration, and keywords.

Contributions to LTER Network and Community Activities - During LTER VII, the KNZ IM (Yang Xia) participated in all annual Information Management Committee (IMC) meetings, served as a member of the IMC Executive Committee (2014 - 2017), an IMC working group tasked with revising the LTER Information Management Review Criteria (renamed to *Guidelines for LTER Information Management Systems*) (2016 - 2017), a committee revising the Guidelines for LTER Website Design and Content (2017 - 2018), the LTER ClimDB/Hydro Database as a database co-administrator (2010 - 2019), and is currently a member of the working group on the next-generation system for meteorology/hydrology data (2018 - present), and a member of the working group on DEIMS (2017 - present).

Future Directions - Planned enhancements and continued improvements to the KNZ IMS for LTER VIII include:

(1) Continuing to ensure data quality, data integrity, and data availability with the latest LTER standards by providing up-to-date, accurate LTER data to KNZ investigators and to the broader scientific community as quickly and efficiently as possible;

(2) Continuing to support researchers and graduate students with the goal of timely incorporation of projects and data into the KNZ IMS and EDI;

(3) Ensuring that KNZ data are PASTA-compliant for the integration of EML 2.1 to 2.2 including a new project funding field, and other additional elements, such as modifying the DEIMS EML generation module;

(4) Upgrading our current Drupal 7 DEIMS site to the latest Drupal 8 or 9 version. As mentioned before, with the recent overhaul of KNZ's data management system and website, our current

system does not need upgraded at this time. However, Drupal 7 will be approaching its end of life in November 2021, requiring an upgrade to KNZ IMS to Drupal 8 or 9 to ensure continued support for updates, security fixes and enhancements. We will utilize the perspective and support from the EDI/DEIMS working group during this transition;

(5) Developing the repository for genetic data and MIxS standards (minimum information about any sequence). Amplicon sequence data will be submitted to the NCBI GenBank database immediately after quality control and finalization of sequence data, and every sequence will be made publically available following GenBank data processing. All molecular microbial data and metadata will be maintained, reported and shared in substance and format that meets the MIxS standards of the Genomic Standards Consortium (GSC) as well as the standards for ready translation to the ecological community (Michener et al. 1997, Yilmaz et al. 2011);

(6) Developing a new spatial data portal to improve geospatial data visualization and integration. The KNZ IM will work with our GIS specialist to develop this spatial data portal which can include more aerial photos, topographic maps, LiDAR, with user-friendly interactive maps available on desktop and mobile devices. Geospatial data will be stored locally in enterprise geodatabases within SQL Server and managed locally. Public accessibility of the KNZ geospatial data will be through a graphic user interface, *Portal for ArcGIS* from Esri. The new KNZ portal site will allow users to access updated geospatial data through database connections or via download. In addition, we are developing web applications that will enable users without GIS knowledge to access KNZ geospatial data with ready to use content for browsing, making maps, field navigation, and analyses.

Table 1. KNZ Information management technical applications, and software.

Servers	2 blade servers with dual 10 core processors (total of 20 processors per machine) 128 GB of ram and mirrored 300GB hard drives in each. These machines make up a 2016 Hyper-V cluster that is running 15 virtual servers, including Ubuntu Linux and windows servers. The blade enclosure includes a domain controller on one blade and a management machine on a separate blade. Each blade has 32 GB of ram, dual 4 core processors and mirrored 300 GB hard drives with 10 GB high speed switches. Each virtual machine serves a specialized function including: a SQL 2012 Database server for Konza data and student data holding, a Konza web server, two Linux servers for current KNZ LTER web server, a spatial data workstation/GIS data server for Konza GIS data and remotely sensed images, a dedicated server for the KPBS weather station, terminal services (32- and 64-bit), and print services, and a Microsoft windows 2016 domain controller for managing local network
Database	SQL Server 2016, MySQL 5.5.62.
Data Storage	EqualLogic SANS with 6 TB virtual machines; 13 TB of configured storage and 8 TB of unconfigured storage for expansion current total storage available 27 TB.
Backups	Daily incremental backups, weekly full backup, monthly back up offsite storage at different location, some large files to be mirrored between servers.
Wireless	K-State provides a secure network for current K-State faculty, staff, and students to use on campus; direct link wireless from KPBS to campus allow researchers to download data to their mail server. All Konza servers are housed in a separate climate-controlled facility with clean power, and managed by the KSU Physics Computer Support Center.
Software	ESRI GIS software (e.g., ArcGIS 10.7), SigmaPlot, SAS, MS Office, Adobe Acrobat, Photoshop, and ERDAS and ENVI software for image processing

Supplementary Document: List of KNZ LTER datasets deposited into the EDI

Table 2. The following table lists all Konza Prairie LTER datasets publicly available through the Environmental Data Initiative (EDI) Data Portal (135 total). For each dataset, EDI package identifier, title, data range, digital object identifier, the creator(s), date of publication, one or more relevant LTER/KNZ Core Area(s), and project status are shown. Datasets utilized by our "Top 10 Publications" are identified with a citation reference listed beneath the dataset DOI.

PackageID	Title, data range available, DOI	Creators	Pub. Year	LTER/ KNZ Core Areas	Status
knb-lter-knz.94.7	**AET01 Konza prairie grass reference evapotranspiration** (2000 - 2018); doi:10.6073/pasta/d57d4368931eda67f103b13f65acff99	Moore, Trisha	2020	Climate/ Hydrology	Ongoing
knb-lter-knz.1.12	**AGW01 Long-term measurement of groundwater physical and chemical properties from wells on watershed N04D at Konza Prairie** (1990 - 2018); doi:10.6073/pasta/7e1ab16f473c2e3c03c6dad79b279db6 Top 10 publication: Macpherson GL, Sullivan PL. 2019. Watershed-scale chemical weathering in a merokarst terrain, northeastern Kansas, USA. Chemical Geology 527:118988	Macpherson, Gwendolyn	2019	Inorganic Nutrients, Climate/ Hydrology	Ongoing
knb-lter-knz.2.12	**AGW02 Measurement of groundwater physical and chemical properties from wells in contrasting land uses near Kings Creek, Konza Prairie** (1996 - 2018); doi:10.6073/pasta/b1190f22889aa9169dcc07766d5b6035	Dodds, Walter	2019	Inorganic Nutrients	Ongoing
knb-lter-knz.90.5	**AGW03 Konza Prairie long-term high frequency groundwater level and temperature from wells on N04D** (2004 - 2017); doi:10.6073/pasta/20b8bf4b57cabf7c8fbd7bd99f09b43e	Macpherson, Gwendolyn	2020	Climate/ Hydrology	Ongoing
knb-lter-knz.102.5	**AMC01 Growing season microclimate by topographic position for annually-burned and 4-yr burned watersheds at Konza Prairie** (2010 - 2013); doi:10.6073/pasta/82d3770b26db865b8b8ab87e1cfd84b7	Nippert, Jesse	2020	Climate/ Hydrology	Complete

knb-lter-knz.3.13	**ANA01 Weekly, seasonal and annual measurement of precipitation volume and chemistry collected as part of the National Atmospheric Deposition Program at Konza Prairie** (1982 - 2019); doi:10.6073/pasta/6759f366220e482e181330e2c0947a2c	Blair, John	2019	Inorganic Nutrients, Climate/ Hydrology	Ongoing
knb-lter-knz.4.13	**APT01 Daily precipitation amounts measured at multiple sites across Konza Prairie** (1982 - 2019); doi:10.6073/pasta/2c5b036a91ebe259e715ff3efbc9c39b Top 10 publication: Knapp AK, Carroll CJ, Griffin-Nolan RJ, Slette IJ, Chaves FA, et al. 2018. A reality check for climate change experiments: Do they reflect the real world? Ecology 99:2145-2151	Nippert, Jesse	2020	Climate/ Hydrology	Ongoing
knb-lter-knz.5.9	**APT02 Monthly temperature and precipitation records from Manhattan, KS** (1891 - 2006); doi:10.6073/pasta/2483e2420b65d82f23513091956138a7	Nippert, Jesse	2018	Climate/ Hydrology	Complete
knb-lter-knz.6.11	**ASD01 Stream discharge for Kings Creek measured at USGS gaging station** (1979 - 2006); doi:10.6073/pasta/bb578a27b289c7f9d65360d75cdb959e	Dodds, Walter	2019	Inorganic Nutrients	Complete
knb-lter-knz.7.11	**ASD02 Stream discharge measured at the flumes on watershed N04D at Konza Prairie** (1985 - 2019); doi:10.6073/pasta/1fb12b7396226b8cb6f785140be36c4c Top 10 publication: Macpherson GL, Sullivan PL. 2019. Watershed-scale chemical weathering in a merokarst terrain, northeastern Kansas, USA. Chemical Geology 527:118988	Dodds, Walter	2020	Disturbance, Inorganic Nutrients, Climate/ Hydrology	Ongoing
knb-lter-knz.8.11	**ASD04 Stream discharge measured at the flumes on watershed N20B at Konza Prairie** (1987 - 2019); doi:10.6073/pasta/03fa19934fafebe716f3bfd791a4d3d9	Dodds, Walter	2020	Disturbance, Inorganic Nutrients, Climate/ Hydrology	Ongoing
knb-lter-knz.9.12	**ASD05 Stream discharge measured at the flumes on watershed N01B at Konza Prairie** (1987 - 2019); doi:10.6073/pasta/5794ee6297c6cabca6169aa2c7cf082c	Dodds, Walter	2020	Disturbance, Inorganic Nutrients, Climate/ Hydrology	Ongoing

knb-lter-knz.10.11	**ASD06 Stream discharge measured at the flumes on watershed N02B at Konza Prairie** (1987 - 2019); doi:10.6073/pasta/0d90c63700f164241074d1f5835c43cb	Dodds, Walter	2020	Disturbance, Inorganic Nutrients, Climate/ Hydrology	Ongoing
knb-lter-knz.11.13	**ASM01 Soil water content measured by neutron probe at Konza Prairie** (1983 - 2017); doi:10.6073/pasta/17ed312f9d601ae172f8fa731577b37b	Nippert, Jesse	2019	Climate/ Hydrology	Ongoing
knb-lter-knz.12.12	**ASR01 Short-term assessment of effects of burning on infiltration, runoff, and sediment and nutrient loss on Tallgrass Prairie using rainfall simulation** (1989); doi:10.6073/pasta/8b3abff4c01ff1f4cfe444070d9d4815	Moore, Trisha	2020	Inorganic Nutrients, Climate/ Hydrology	Complete
knb-lter-knz.20.5	**ASS01 Suspended sediments in streams impacted by prescribed burning, grazing and woody vegetation removal at Konza Prairie** (2009- 2017); doi:10.6073/pasta/ab4f9d5891fdbc98e6d96e796e93299f	Dodds, Walter	2019	Disturbance, Inorganic Nutrients	Ongoing
knb-lter-knz.13.13	**AST01 Soil temperature measured in burned, burned-clipped, and unburned plots at Konza Prairie** (1987 - 1993); doi:10.6073/pasta/c262c2453bb8146716a3056b3b36c298	Blair, John	2019	Disturbance, Climate/ Hydrology	Complete
knb-lter-knz.21.6	**ASW01 Stream water quality at the flumes on watersheds N04D and N02B and at the Shane Creek crossing on watershed SA at Konza Prairie** (2008 - 2010); doi:10.6073/pasta/c0a37672acf4c6b7233439707100fcd3	Dodds, Walter	2019	Inorganic Nutrients	Complete
knb-lter-knz.14.16	**AWE01 Meteorological data from the Konza Prairie headquarters weather station** (1982 - 2019); doi:10.6073/pasta/297c4e318a62b80340bba6ba5184a37d Top 10 publication: Macpherson GL, Sullivan PL. 2019. Watershed-scale chemical weathering in a merokarst terrain, northeastern Kansas, USA. Chemical Geology 527:118988	Nippert, Jesse	2020	Climate/ Hydrology	Ongoing

knb-lter-knz.16.11	**AWT02 Water temperature measured continuously in Konza Prairie streams** (1986 - 2000); doi:10.6073/pasta/f57e26052916d81fa9b5e1f78fdc6422	Dodds, Walter	2019	Climate/ Hydrology	Complete
knb-lter-knz.17.11	**BGPVC Plant species composition in the Belowground Plot Experiment at Konza Prairie** (1989 - 2019); doi:10.6073/pasta/1ee5e3273f9325759af042b311c70bf9 Top 10 publication: Komatsu KJ, Avolio ML, Lemoine NP, Isbell F, Grman E, Houseman GR, ... & Anderson JP. 2019. Global change effects on plant communities are magnified by time and the number of global change factors imposed. Proceedings of the National Academy of Sciences, 116(36), 17867-17873	Blair, John	2020	Disturbance, Populations	Ongoing
knb-lter-knz.18.10	**BMS01 Mycorrhizae spore density and composition in the Belowground Plot Experiment at Konza Prairie** (1987 - 1995); doi:10.6073/pasta/02aa35f94b5b219755356394a52462bb	Hartnett, David	2019	Disturbance, Populations	Complete
knb-lter-knz.19.10	**BNS01 Nematodes density and composition in the Belowground Plot Experiment at Konza Prairie** (1987 - 1994); doi:10.6073/pasta/899e126420d530bf9da82ccc9f2bfe3d	Todd, Timothy	2018	Disturbance, Populations	Complete
knb-lter-knz.23.10	**CBC01 Weekly record of bird species observed on Konza Prairie** (1971 - 1996); doi:10.6073/pasta/4c1a176b8c787394b5c0f8202dfa1dcb	Boyle, Alice	2019	Populations	Complete
knb-lter-knz.24.12	**CBD01 Date of occurrence for bird species observed on Konza Prairie** (1971 - 1992); doi:10.6073/pasta/e54eacdfd0163dc038ca9f1b880a9f9b	Boyle, Alice	2019	Populations	Complete
knb-lter-knz.78.11	**CBH01 Konza Prairie bison herd information** (1994 - 2019); doi:10.6073/pasta/178f3bac82657d928d3585e901e195ef	Blair, John	2020	Populations	Ongoing

knb-lter-knz.107.1	**CBM01 Plains bison movement patterns in an experimental heterogeneous landscape at Konza Prairie** (2008 - 2013); doi:10.6073/pasta/84cd323fa8476eb7c2cf7ff1e8cc714e	Joern, Anthony	2019	Disturbance	Complete
knb-lter-knz.25.10	**CBN01 Records of breeding activities for birds on Konza** (1971 - 1992); doi:10.6073/pasta/3d4a3dae33f70fe4bbd3c3a9b1fb5381	Sandercock, Brett	2020	Populations	Complete
knb-lter-knz.26.11	**CBP01 Variable distance line-transect sampling of bird population numbers in different habitats on Konza Prairie** (1981 - 2009); doi:10.6073/pasta/d966d18585729a2a29eead60f4764f14	Boyle, Alice	2019	Populations	Complete
knb-lter-knz.111.2	**CBS01 Capture records of (mainly) Grasshopper Sparrows on Konza Prairie** (2013 - 2017); doi:10.6073/pasta/9e9076dc118db61e08ab8eea794f371b	Boyle, Alice	2019	Populations	Ongoing
knb-lter-knz.112.2	**CBS02 Nests of Grasshopper Sparrows on Konza Prairie** (2013 - 2017); doi:10.6073/pasta/a769edd37be5af1c9c83998c6210341b	Boyle, Alice	2019	Populations	Ongoing
knb-lter-knz.113.2	**CBS03 Grasshopper Sparrow surveys: densities, reproductive index, and locations of marked individuals on Konza Prairie** (2013 - 2017); doi:10.6073/pasta/df48310bc15692f585fa411d00b4cdd9	Boyle, Alice	2019	Populations	Complete
knb-lter-knz.114.2	**CBS04 Sweep sample data: prey estimates for Grasshopper Sparrows on Konza Prairie** (2014 - 2018); doi:10.6073/pasta/917537f85fb73847ac678b51b3dcf07b	Boyle, Alice	2019	Disturbance, Populations	Ongoing
knb-lter-knz.115.2	**CBS05 Estimates of vegetation structure and composition collected on Konza Prairie watersheds and on the nearby Rannell's Preserve** (2014 - 2017); doi:10.6073/pasta/01311bfbc1ea745a17eed36e9f069d83	Boyle, Alice	2019	Disturbance, Populations	Ongoing

knb-lter-knz.128.3	**CEE01 The Climate Extremes Experiment (CEE): Assessing ecosystem resistance and resilience to repeated climate extremes at Konza Prairie** (2010 - 2018); doi:10.6073/pasta/57bbbfcf22783a52ad09d7239073a5de Top 10 publication: Hoover DL, Knapp AK, Smith MD. 2014 Resistance and resilience of a grassland ecosystem to climate extremes. Ecology 95:2646 -2656	Smith, Melinda; Knapp, Alan	2020	Primary Production, Disturbance, Populations	Ongoing
knb-lter-knz.130.6	**CFC01 Kings Creek long-term fish and crayfish community sampling at Konza Prairie** (1995 - 2019); doi:10.6073/pasta/942557a3170aaab54e91ff471bf27444	Gido, Keith	2019	Populations	Ongoing
knb-lter-knz.87.8	**CFP01 Fish population on selected watersheds at Konza Prairie** (1995 - 2018); doi:10.6073/pasta/be5ad393af83f9602aae96423a280875	Gido, Keith	2019	Populations	Ongoing
knb-lter-knz.27.11	**CGP01 Gall-insect densities on selected plant species in watersheds with different fire frequencies** (1988 - 1996); doi:10.6073/pasta/b2ac9e918a66dbbb18c7a6b39dc1efab	Hartnett, David	2018	Disturbance, Populations	Complete
knb-lter-knz.28.12	**CGR01 Sweep sampling of grasshoppers on Konza Prairie LTER watersheds** (1981); doi:10.6073/pasta/03184e754631436a0bf91c88300566e0	Joern, Anthony	2018	Disturbance, Populations	Complete
knb-lter-knz.29.14	**CGR02 Sweep sampling of grasshoppers on Konza Prairie LTER watersheds** (1982 - 2017); doi:10.6073/pasta/7b2259dcb0e499447e0e11dfb562dc2f	Joern, Anthony	2019	Disturbance, Populations	Ongoing
knb-lter-knz.30.11	**CGR03 Effects of spring burning on Grasshopper Nymphs** (1982); doi:10.6073/pasta/21b1e4b34c8cd31c3d4c8d86ea855b65	Joern, Anthony	2018	Disturbance, Populations	Complete
knb-lter-knz.32.10	**CGR05 Effects of fire frequency on composition of grasshopper assemblages** (1983); doi:10.6073/pasta/eea92a19b6a2abb06cae51680668007c	Joern, Anthony	2018	Disturbance, Populations	Complete

knb-lter-knz.33.11	**CMY01 Mycorrhizal colonization and plant community responses to long-term suppression of Mycorrhizal Fungi** (1991 - 1995); doi:10.6073/pasta/dbaaff27622cbd5248f5ec0d67ffae11	Wilson, Gail	2018	Primary Production, Populations	Complete
knb-lter-knz.34.11	**CPC01 Annual census of greater prairie chickens on leks at Konza Prairie** (1981 - 2008); doi:10.6073/pasta/68ae69ec0904edeeeba78258faf04bb9	Boyle, Alice	2018	Populations	Complete
knb-lter-knz.35.8	**CPC02 Census of greater prairie chicken on leks at Konza Prairie** (2000 - 2004); doi:10.6073/pasta/1b8778fc2260451d47d0f7bc08f0aa89	Boyle, Alice	2018	Populations	Complete
knb-lter-knz.37.10	**CSA02 Soil macroarthropod densities and biomass on annually burned and unburned watersheds** (1981 - 1983); doi:10.6073/pasta/338e93ec365042280987222ed8cdc1a9	Blair, John	2018	Disturbance, Populations	Complete
knb-lter-knz.88.8	**CSM01 Seasonal summary of numbers of small mammals on 14 LTER traplines in prairie habitats at Konza Prairie** (1981 - 2013); doi:10.6073/pasta/9735a16a0018d85ff5efb8b74fd100f4	Kaufman, Donald	2019	Disturbance, Populations	Complete
knb-lter-knz.86.7	**CSM02 Seasonal summary of numbers of small mammals on the four LTER gallery forest and limestone ledges traplines in wooded habitats at Konza Prairie** (1981 - 1988); doi:10.6073/pasta/bf6caddba088fb97b2ae774d8fb2a3d4	Kaufman, Donald	2019	Disturbance, Populations	Complete
knb-lter-knz.85.6	**CSM03 Seasonal summary of numbers of small mammals on the two LTER traplines in planted grassland (Brome fields) habitats at Konza Prairie** (1981 - 1986); doi:10.6073/pasta/258e398ad4e155dd0857d5bedab86323	Kaufman, Donald	2019	Disturbance, Populations	Complete

knb-lter-knz.38.13	**CSM04 Seasonal summary of numbers of small mammals on the eight LTER seasonal burn traplines in prairie habitats at Konza Prairie** (1994 - 2011); doi:10.6073/pasta/5db599009d5c1652e62b1b51b08429c5	Kaufman, Donald	2019	Disturbance, Populations	Complete
knb-lter-knz.84.7	**CSM05 Seasonal summary of numbers of small mammals on the six LTER traplines in prairie habitats on which fire regime has been reversed at Konza Prairie** (1999 - 2010); doi:10.6073/pasta/89846e133f48edf3de8fc96e69cf1204	Kaufman, Donald	2019	Disturbance, Populations	Complete
knb-lter-knz.83.5	**CSM06 Seasonal summary of numbers of small mammals on miscellaneous traplines in prairie habitats that were trapped from 1 to 11 years at Konza Prairie** (1981 - 1993); doi:10.6073/pasta/8166f11287117b284e120e0a35e31e45	Kaufman, Donald	2019	Disturbance, Populations	Complete
knb-lter-knz.99.3	**CSM08 Small mammal host-parasite sampling data for 16 linear trapping transects located in 8 LTER burn treatment watersheds at Konza Prairie** (2016 - 2018); doi:10.6073/pasta/69109c56fcf21a30a8d37369cb47f8de	Hope, Andrew	2019	Disturbance, Populations	Ongoing
knb-lter-knz.400.3	**EJR01 Foraging decisions underlying restricted space-use: effects of fire and forage maturation on large herbivore nutrient uptake on Konza Prairie** (2012 - 2013); doi:10.6073/pasta/6f0f46aa9b7bdd3d63fcc4a1b6084c99	Raynor, Edward; Joern, Anthony	2019	Disturbance	Complete
knb-lter-knz.133.2	**ESM01 Fire and grazing modulate the structure and resistance of plant-floral visitor networks in a tallgrass prairie** (2014); doi:10.6073/pasta/d67f76feaaff1767571b97b640f622dd Top 10 publication: Welti EAR, Qiu F, Tetreault HM, Ungerer M, Blair JM, Joern A. 2019 Fire, grazing, and climate shape plant-grasshopper interactions in a tallgrass prairie. Functional Ecology 33:735-745	Welti, Ellen; Joern, Anthony	2019	Disturbance, Populations	Complete

knb-lter-knz.105.1	**FWE01 Effects of browsing and fire on woody encroachment at Konza Prairie** (2015 - 2018); doi:10.6073/pasta/7ec1d77684c30eb707468f72db101bb0	Nippert, Jesse; O'Connor, Rory	2019	Disturbance, Populations	Complete
knb-lter-knz.101.1	**GFE01 Ghost Fire: an experimental manipulation of fire effects on multi-trophic community dynamics in the ungrazed uplands of unburned and annually burned watersheds of Konza Prairie** (2014 - 2018); doi:10.6073/pasta/ade02dd01e52fa85f7a1ef912f246a03	Koerner, Sally; Avolio, Meghan; Hoover, David; Komatsu, Kimberly; Smith, Melinda; Wilcox, Kevin; Zeglin, Lydia	2019	Primary Production, Disturbance, Populations	Ongoing
knb-lter-knz.200.6	**GIS00 GIS coverages defining the site boundary of Konza Prairie** (1977 - 2019); doi:10.6073/pasta/e56e5d4b84f0cf7abf6533f675fe0e0d	Blackmore, Pam	2019	GIS	Ongoing
knb-lter-knz.201.7	**GIS01 GIS coverages defining internal boundaries of Konza Prairie** (1977 - 2019); doi:10.6073/pasta/575505539080e47e02cb2d37bcb42bff	Blackmore, Pam	2020	Disturbance, GIS	Ongoing
knb-lter-knz.202.8	**GIS02 GIS coverages defining the Konza Prairie experimental watershed treatments** (1977 - 2019); doi:10.6073/pasta/0c478c8ebe2797af8a8e0943bdf1888c	Blackmore, Pam	2019	GIS	Ongoing
knb-lter-knz.205.9	**GIS05 GIS coverages defining Konza Prairie burn history** (1977 - 2019); doi:10.6073/pasta/ecb7dbb9f1729cdd26a3a5da5779710c	Blackmore, Pam	2020	Disturbance, GIS	Ongoing
knb-lter-knz.210.6	**GIS10: GIS coverage defining roads in and around Konza Prairie** (1977 - 2018); doi:10.6073/pasta/2fa78c459b4260775d21d1a492046f98	Blackmore, Pam	2019	GIS	Ongoing
knb-lter-knz.211.8	**GIS11: A GIS coverage defining nature trails on Konza Prairie** (1982 - 2018); doi:10.6073/pasta/695f7d7130940f1d2e291c058fd55382	Blackmore, Pam	2019	GIS	Ongoing

knb-lter-knz.213.5	**GIS13 GIS coverages defining Konza wildfire and supplementary burn history** (1977 - 2018); doi:10.6073/pasta/a7a8d418db66e2d04fbb251f96111501	Blackmore, Pam	2019	Disturbance, GIS	Ongoing
knb-lter-knz.219.4	**GIS19 A GIS coverage defining permanent structures on Konza Prairie** (1977 - 2019); doi:10.6073/pasta/ae7668d5280317e7e566b7fad21191a0	Blackmore, Pam	2020	Disturbance, GIS	Ongoing
knb-lter-knz.220.4	**GIS20 GIS coverages defining Konza elevations** (2006 - 2019); doi:10.6073/pasta/f11596621709ba6e4ac48e9f2e898a7a	Blackmore, Pam	2019	GIS	Ongoing
knb-lter-knz.221.4	**GIS21 GIS coverages defining water bodies on Konza Prairie** (1972 - 2016); doi:10.6073/pasta/8ad9392cc5fbd31db4239b1056514ede	Briggs, John	2016	GIS	Ongoing
knb-lter-knz.222.5	**GIS22 GIS coverage defining soils (SSURGO) on Konza Prairie** (1982 - 2019); doi:10.6073/pasta/7642688193598253056343aa30285122	Blackmore, Pam	2019	Inorganic Nutrients, GIS	Ongoing
knb-lter-knz.230.5	**GIS30 GIS coverages defining sample locations for abiotic datasets on Konza Prairie** (1972 - 2020); doi:10.6073/pasta/d97e3334793585fc93afee3afa52311c	Blackmore, Pam	2020	Inorganic Nutrients, Climate/ Hydrology, GIS	Ongoing
knb-lter-knz.235.5	**GIS35 GIS coverages defining sample locations for belowground datasets on Konza Prairie** (1982 - 2019); doi:10.6073/pasta/5a742e35fcc97c715e8b12c4fea098cd	Blackmore, Pam	2019	Disturbance, Populations, GIS	Ongoing

knb-lter-knz.240.6	**GIS40 GIS coverages defining the sample locations of Konza consumer data** (1982 - 2019); doi:10.6073/pasta/4be20b4afb176e9c2ed0770614b7df9d	Blackmore, Pam	2019	Disturbance, Populations, GIS	Ongoing
knb-lter-knz.245.6	**GIS45 GIS coverages defining the Konza nutrient data sample locations** (1982 - 2019); doi:10.6073/pasta/5507906b47e9ba03389d932d17900872	Blackmore, Pam	2019	Organic Matter, Disturbance, Inorganic Nutrients, GIS	Ongoing
knb-lter-knz.250.5	**GIS50 coverages defining the Konza producer data sample locations** (1982 - 2019); doi:10.6073/pasta/055863323411e9a932ce1767b5d0810c	Blackmore, Pam	2020	Primary Production, Disturbance, GIS	Ongoing
knb-lter-knz.255.4	**GIS55 GIS coverages defining the Konza HQ irrigation system** (1982 - 2019); doi:10.6073/pasta/fb9fab4cb2d62779b3e736a2035b2634	Blackmore, Pam	2019	Primary Production, Organic Matter, Populations, GIS	Ongoing
knb-lter-knz.260.4	**GIS60 GIS coverages defining other Konza sample and research areas** (1982 - 2019); doi:10.6073/pasta/df43d5b3cf2f5206b7a3caad550c6e33	Blackmore, Pam	2020	Disturbance, Inorganic Nutrients, Populations, Climate/ Hydrology, GIS	Ongoing
knb-lter-knz.142.1	**GIS68 GIS coverages of Konza Prairie research experiments** (2020); doi:10.6073/pasta/65010b008dae868c76e4b7676576de37	Blackmore, Pam	2020	Primary Production, Disturbance, Inorganic Nutrients, Populations, Climate/ Hydrology, GIS	Ongoing
knb-lter-knz.143.1	**GIS70 Konza Prairie woody plant mapping in core watersheds (1D, 20B, and 4B)** (2019); doi:10.6073/pasta/4adc5f95851b35e7c581385cffec7d69	Blackmore, Pam	2020	Disturbance, GIS	Ongoing

knb-lter-knz.103.2	**HRE01 Environmental heterogeneity restoration experiment at Konza Prairie** (1998 - 2017); doi:10.6073/pasta/3d6c828030fbdcc7a8b71e262978e848 Top 10 publication: Baer SG, Blair JM, Collins SL. 2016 Environmental heterogeneity has a weak effect on diversity during community assembly in tallgrass prairie. Ecological Monographs 86:94 -106 Top 10 publication: Komatsu KJ, Avolio ML, Lemoine NP, Isbell F, Grman E, Houseman GR, ... & Anderson JP. 2019 Global change effects on plant communities are magnified by time and the number of global change factors imposed. Proceedings of the National Academy of Sciences, 116(36), 17867-17873	Baer, Sara	2020	Primary Production	Ongoing
knb-lter-knz.42.9	**KFH01 Konza Prairie fire history** (1972 - 2019); doi:10.6073/pasta/42a562e9a41e4f37f81fd41d84b6499d	Blair, John; O'Neal, Patrick	2019	Disturbance	Ongoing
knb-lter-knz.73.3	**KIC01 Konza Prairie terrestrial arthropods species list** (1977 - 2016); doi:10.6073/pasta/bd0a961d45f9e381ee1645dbd27ac461	Joern, Anthony	2018	Populations	Ongoing
knb-lter-knz.131.3	**KKE01 The Konza-Kruger Experiment: A cross-continental fire and grazing experiment at Konza Prairie** (2006 - 2013); doi:10.6073/pasta/02bbdc00f35af065d9bb366042f13e5b	Smith, Melinda; Koerner, Sally	2019	Primary Production, Disturbance	Complete
knb-lter-knz.135.1	**KKE02 The Konza-Kruger Experiment: Net primary production data** (2010 - 2011); doi:10.6073/pasta/4daea9662792cac94b6651a1073b79dd	Blair, John; Smith, Melinda; Collins, Scott; Knapp, Alan	2019	Primary Production, Populations	Complete
knb-lter-knz.136.1	**KKE03 The Konza-Kruger Experiment: Kruger species composition** (2006 - 2010); doi:10.6073/pasta/7d9467fe079f7dd83560f805e0f79b7e	Blair, John; Collins, Scott; Knapp, Alan; Smith, Melinda	2019	Populations	Complete

knb-lter-knz.44.8	**NBC01 Konza Prairie Belowground Plot Experiment: Soil chemistry responses to experimental manipulations of fire, nutrients and mowing** (1987); doi:10.6073/pasta/a02e3894a0fe85444bac2155d0f0e5d5	Blair, John	2019	Disturbance, Inorganic Nutrients	Complete
knb-lter-knz.43.5	**NBP01 Nitrogen and phosphorus in bulk precipitation at Konza Prairie** (1982 - 2018); doi:10.6073/pasta/e4760450aeb943e16c2e04833f6780c3	Blair, John	2019	Inorganic Nutrients, Climate/ Hydrology	Ongoing
knb-lter-knz.45.8	**NBS01 Belowground Plot Experiment: Soil water chemistry from lysimeters** (1997 - 1998); doi:10.6073/pasta/715c42c48566c3cce6afdca30f5bc5a1	Blair, John	2019	Disturbance, Inorganic Nutrients	Complete
knb-lter-knz.129.1	**NGE01 Chronic Addition of Nitrogen Gradient Experiment (ChANGE): Assessing threshold responses of plant community composition and ecosystem processes at Konza Prairie** (2013 - 2016); doi:10.6073/pasta/06af1cd9c31d04bcdad89bf54ab95a53	Smith, Melinda	2018	Primary Production, Disturbance, Populations	Ongoing
knb-lter-knz.46.9	**NPL01 Litterfall inputs to soil surface in watersheds with different fire treatments** (1981 - 1991); doi:10.6073/pasta/3c8f3b87b86ac06be888f5da6c038970	Blair, John	2019	Organic Matter, Inorganic Nutrients	Complete
knb-lter-knz.47.9	**NSC01 Chemistry and physical characteristics of soils from Konza LTER watersheds with different fire and grazing treatments** (1982 - 2015); doi:10.6073/pasta/accc92110cda13cb0b149c658afb17c0	Blair, John	2019	Organic Matter, Disturbance, Inorganic Nutrients	Ongoing
knb-lter-knz.48.8	**NSW01 Soil water chemistry from porous cup lysimeters on watersheds with different fire treatment** (1982 - 1989); doi:10.6073/pasta/dc5bccadd5943704e12ec9c2d94fc4ad	Blair, John	2019	Inorganic Nutrients	Complete
knb-lter-knz.49.8	**NTF01 Volume and chemistry of throughfall in tallgrass Pprairie** (1982 - 1995); doi:10.6073/pasta/84448d7b0df1d11460404689c9e1e64b	Blair, John	2019	Inorganic Nutrients, Climate/ Hydrology	Complete

knb-lter-knz.100.3	**NUT01 Nutrient Network: Investigating the roles of nutrient availability and vertebrate herbivory on grassland structure and function at Konza Prairie** (2007 - 2018); doi:10.6073/pasta/f610d9d204d53dca4b51e3c211334a7e	Komatsu, Kimberly; Smith, Melinda	2019	Primary Production, Inorganic Nutrients, Populations	Ongoing
knb-lter-knz.50.13	**NWC01 Stream water chemistry for the King's Creek drainage basin on Konza Prairie** (1983 - 2018); doi:10.6073/pasta/bb6b065e5b25234dd1bb80ff476933e0	Dodds, Walter	2019	Inorganic Nutrients	Ongoing
knb-lter-knz.51.8	**NWC02 Stream water conductivity for the King's Creek drainage basin on Konza Prairie** (1983 - 1993); doi:10.6073/pasta/2341098575190e919b135333ceda0462	Dodds, Walter	2018	Inorganic Nutrients	Complete
knb-lter-knz.53.8	**OMB01 Microbial biomass in the Belowground Plot Experiment at Konza Prairie** (1989-1999); doi:10.6073/pasta/f395e5c806b79c4cc70eb8b14a216eb6	Rice, Charles	2019	Organic Matter, Inorganic Nutrients	Complete
knb-lter-knz.54.7	**OPD01 Konza Prairie standing dead and litter decomposition** (1982-1983); doi:10.6073/pasta/d253a92c349fc2e22aae20d8e60a550b	Blair, John	2018	Organic Matter	Complete
knb-lter-knz.55.12	**PAB01 Aboveground net primary productivity of tallgrass prairie based on accumulated plant biomass on core LTER watersheds (001d, 004b, 020b)** (1984 - 2017); doi:10.6073/pasta/38de94ec00e7d553197910b835c37b7d Top 10 publication: Knapp AK, Carroll CJ, Griffin-Nolan RJ, Slette IJ, Chaves FA, et al. 2018. A reality check for climate change experiments: Do they reflect the real world? Ecology 99:2145-2151	Blair, John; Nippert, Jesse	2020	Primary Production	Ongoing

knb-lter-knz.77.12	**PAB02 Biweekly measurement of aboveground net primary productivity on an unburned and annually burned watershed at Konza Prairie** (1984 - 2000); doi:10.6073/pasta/37e8c3186831903142d9c4f2e22cfff0	Knapp, Alan	2019	Primary Production, Disturbance	Complete
knb-lter-knz.76.12	**PAB03 Aboveground primary productivity of tallgrass prairie based on accumulated plant biomass on LTER watersheds burned at different seasons** (1994 - 2015); doi:10.6073/pasta/6a58f244c4caff015bc20c980b3f253f	Blair, John; Nippert, Jesse	2018	Primary Production, Disturbance	Ongoing
knb-lter-knz.56.5	**PAB04 Aboveground primary productivity of tallgrass prairie based on accumulated plant biomass on miscellaneous LTER watersheds** (1984 - 2014); doi:10.6073/pasta/05b98e85c58006fda46d47a0ba9d950a	Nippert, Jesse	2019	Primary Production	Ongoing
knb-lter-knz.98.5	**PAB05 Aboveground net primary productivity of tallgrass prairie based on accumulated plant biomass on the LTER fire reversal experiment watersheds** (1997 - 2016); doi:10.6073/pasta/3f119e0c0f6c90164d281d16f720a9ee Top 10 publication: Koerner SE, Avolio ML, La Pierre KJ, Wilcox KR, Smith MD, & Collins SL 2016. Nutrient additions cause divergence of tallgrass prairie plant communities resulting in loss of ecosystem stability. Journal of Ecology 104(5), 1478-1487	Nippert, Jesse	2019	Primary Production, Disturbance	Ongoing
knb-lter-knz.57.10	**PBB01 Belowground Plot Experiment: Aboveground net primary productivity of tallgrass prairie based on accumulated plant biomass** (1986 - 2017); doi:10.6073/pasta/2cfddc73f7d3c391827991bcc835f571	Blair, John; Zeglin, Lydia	2020	Primary Production, Disturbance	Ongoing
knb-lter-knz.58.8	**PBB02 Belowground Plot Experiment: Biomass and nutrient content of Rhizomes** (1987 - 1994); doi:10.6073/pasta/8d6ded9a2f120fdc84c1b08d6477ca03	Rice, Charles; Zeglin, Lydia	2019	Primary Production, Disturbance, Inorganic Nutrients	Complete

knb-lter-knz.59.8	**PBB03 Belowground Plot Experiment: Belowground plot experiment: biomass and nutrient content of roots** (1989 - 1994); doi:10.6073/pasta/5d98d20fe5038479cb06b014a3bc3a52	Rice, Charles; Zeglin, Lydia	2019	Primary Production, Disturbance, Inorganic Nutrients	Complete
knb-lter-knz.62.11	**PBG01 Plant species composition in the Patch-Burn Grazing Experiment at Konza Prairie** (2008 - 2018); doi:10.6073/pasta/8841ad5b3734a7aa940870d990c9e74f	Blair, John	2019	Disturbance, Populations	Ongoing
knb-lter-knz.116.3	**PBG02 Aboveground primary productivity within permanent and rotating grazing exclosures in the Patch-Burn Grazing Experiment at Konza Prairie** (2010 - 2013); doi:10.6073/pasta/d3cd2324368f383e06405dbf856fb4c9	Hartnett, David	2019	Primary Production, Disturbance	Ongoing
knb-lter-knz.117.5	**PBG03 Disk pasture meter measurements to estimate plant standing biomass in the Patch-Burn Grazing experiment at Konza Prairie** (2011 - 2019); doi:10.6073/pasta/74e5038ee6e024f3d264992201b0b43d	Joern, Anthony; Nippert, Jesse	2020	Primary Production, Disturbance	Ongoing
knb-lter-knz.118.5	**PBG04 Reproductive effort of Big Bluestem, Indiangrass and Little Bluestem in the Patch-Burn Grazing Experiment at Konza Prairie** (2012 - 2016); doi:10.6073/pasta/635f3f15895ec88280390852e2ed22e3	Hartnett, David	2019	Primary Production, Disturbance, Populations	Ongoing
knb-lter-knz.119.2	**PBG05 Response of bird abundance to the Patch-Burn Grazing experiment at Konza Prairie** (2011 - 2016); doi:10.6073/pasta/e1906e4a5b59ae1d136a0c4a1dd7f4b7	Jensen, William; Verheijen, Bram	2019	Disturbance, Populations	Ongoing
knb-lter-knz.120.1	**PBG06 Cattle grazing and cattle performance in the Patch-Burn Grazing experiment at Konza Prairie** (2010 - 2018); doi:10.6073/pasta/6cce923ed46a0ae22f034f7b1acc9636	Olson, K C	2020	Disturbance, Populations	Ongoing

knb-lter-knz.121.4	**PBG07 Grasshopper species abundances in the Patch-Burn Grazing experiment at Konza Prairie** (2010 - 2017); doi:10.6073/pasta/3d41c0996f64310d733a5343c884606f	Joern, Anthony	2020	Disturbance, Populations	Ongoing
knb-lter-knz.122.3	**PBG08 Grasshopper density survey in the Patch-Burn Grazing experiment at Konza Prairie** (2010 - 2019); doi:10.6073/pasta/69f8c8ee8f7b981d050f45e6419bd8e5	Joern, Anthony; Nippert, Jesse	2020	Disturbance, Populations	Ongoing
knb-lter-knz.124.2	**PBG10 Soil physical and chemical characteristics in the Patch-Burn Grazing experiment at Konza Prairie** (2010 - 2015); doi:10.6073/pasta/3836f39450ae83ed075c4ce081b0bfb0	Blair, John	2019	Organic Matter, Disturbance	Ongoing
knb-lter-knz.125.2	**PBG11 Stream water chemistry for the Shane Creek drainage basin in the Patch-Burn Grazing experiment at Konza Prairie** (2009 - 2017); doi:10.6073/pasta/3230dc55884d769171413b04e67a17a1	Dodds, Walter	2019	Disturbance, Climate/Hydrology	Ongoing
knb-lter-knz.60.8	**PEB01 Aboveground net primary productivity of tallgrass prairie based on accumulated plant biomass in grazing exclosures on bison-grazed watershed**s (1992 - 2012); doi:10.6073/pasta/1be621ce275d0a3950e6dfb50093cb65	Hartnett, David	2019	Primary Production, Disturbance	Ongoing
knb-lter-knz.61.8	**PFS01 Reproductive effort of Big Bluestem, Indiangrass, and Little Bluestem on belowground plots** (1986 - 1988); doi:10.6073/pasta/7e08ee0f7b1db091519d2db1ecffafa5	Hartnett, David	2018	Primary Production, Populations	Complete
knb-lter-knz.63.11	**PGL01 Litterfall collection in riparian gallery forest at Konza Prairie** (1981 - 2017); doi:10.6073/pasta/fa4de4bd9e14442ec9deb2af218b9ee3	Nippert, Jesse	2020	Primary Production, Organic Matter	Ongoing
knb-lter-knz.64.9	**PPH01 Phenology of selected plant species at Konza Prairie** (1981 - 1987); doi:10.6073/pasta/1a0eba81a3648722b149cd59581014a0	Nippert, Jesse	2019	Populations, Climate/Hydrology	Complete

knb-lter-knz.127.2	**PPL01 Konza Prairie long-term Phosphorus Plots Experiment** (2002 - 2018); doi:10.6073/pasta/16cf0739e6db87e91f15c0aed9442482 Top 10 publication: Komatsu KJ, Avolio ML, Lemoine NP, Isbell F, Grman E, Houseman GR, ... & Anderson JP. 2019. Global change effects on plant communities are magnified by time and the number of global change factors imposed. Proceedings of the National Academy of Sciences, 116(36), 17867-17873	Avolio, Meghan	2019	Primary Production, Inorganic Nutrients, Populations	Ongoing
knb-lter-knz.134.1	**PPS01 Konza Prairie plant species list** (1971 - 2019); doi:10.6073/pasta/60a4887a6843f6fa9f660626ecf38b7a	Nippert, Jesse; Blair, John; Taylor, Jeffrey	2019	Primary Production, Disturbance, Populations	Ongoing
knb-lter-knz.95.12	**PRE02 Reproductive effort of Big Bluestem, Indiangrass and Little Bluestem on selected Konza Prairie LTER watersheds** (1982 - 2017); doi:10.6073/pasta/1d7aa3fcff6a00d392ec97a5f138a570	Hartnett, David	2020	Primary Production, Populations	Ongoing
knb-lter-knz.82.3	**PRP01 Konza Prairie long-term restoration study of aboveground annual net primary productivity (ANPP)** (1998 - 2012); doi:10.6073/pasta/3dad1cd5dba71b00bcbcf063fff0ede8	Baer, Sara; Blair, John; Collins, Scott	2019	Primary Production, Disturbance	Complete
knb-lter-knz.66.9	**PRW01 Fine root density and turnover based on root window observations** (1986 - 1989); doi:10.6073/pasta/47361866365740006c8e434b8a676026	Blair, John	2019	Primary Production, Organic Matter	Complete
knb-lter-knz.67.10	**PTN01 Aboveground net primary productivity along transects spanning topographic gradients on an annually burned and unburned watershed at Konza Prairie** (1989 - 1997); doi:10.6073/pasta/77a3caa711db3a1c0299ce0d1a3b086f	Blair, John	2019	Primary Production, Disturbance	Complete

knb-lter-knz.68.10	**PVC01 Plant species composition on selected watersheds at Konza Prairie** (1981); doi:10.6073/pasta/4f58e441eddbbf6b5abbb32ce746e068	Hartnett, David; Ratajczak, Zak	2020	Disturbance, Populations	Complete
knb-lter-knz.69.17	**PVC02 Plant species composition on selected watersheds at Konza Prairie** (1983 - 2019); doi:10.6073/pasta/575450f063c79c06c5b15a37f5a54235 Top 10 publication: Ratajczak Z, D'Odorico P, Collins SL, Bestelmeyer BT, Isbell FI, Nippert JB. 2017. The interactive effects of press/pulse intensity and duration on regime shifts at multiple scales. Ecological Monographs 87(2):198-218; Top 10 publication: Koerner SE, Avolio ML, La Pierre KJ, Wilcox KR, Smith MD, & Collins SL 2016. Nutrient additions cause divergence of tallgrass prairie plant communities resulting in loss of ecosystem stability. Journal of Ecology 104(5), 1478-1487	Hartnett, David; Collins, Scott; Ratajczak, Zak	2020	Primary Production, Disturbance	Ongoing
knb-lter-knz.70.10	**PWV01 Cover of woody vegetation at Konza Prairie** (1981 - 1986); doi:10.6073/pasta/e64fe7c9ba9bb502671aabcd9ae2badf	Nippert, Jesse; Ratajczak, Zak	2020	Primary Production, Disturbance, Populations	Complete
knb-lter-knz.71.7	**PWV02 Importance values of gallery forest vegetation at Konza Prairie** (1983); doi:10.6073/pasta/bdf7220eead9b3ed2beb9b45708394cd	Briggs, John	2019	Populations	Complete
knb-lter-knz.132.2	**RCS01 Recovery and relative influence of root, microbial, and structural properties of soil on physically sequestered carbon stocks in restored grassland at Konza Prairie** (2013 - 2017); doi:10.6073/pasta/6d42e250c2abf7271b459b29bac2f4c1	Scott, Drew; Baer, Sara; Blair, John	2018	Organic Matter, Disturbance	Complete

knb-lter-knz.106.2	**RMP01 Rainfall manipulation plot study at Konza Prairie** (1997 - 2012); doi:10.6073/pasta/fdd3a94b43a9b67ac8fef6787790a682 Top 10 publication: Komatsu KJ, Avolio ML, Lemoine NP, Isbell F, Grman E, Houseman GR, ... & Anderson JP. 2019. Global change effects on plant communities are magnified by time and the number of global change factors imposed. Proceedings of the National Academy of Sciences, 116(36), 17867-17873	Smith, Melinda; Collins, Scott; Blair, John	2018	Primary Production, Populations	Complete
knb-lter-knz.145.1	**SMR01 Konza Prairie grassland soil microbial responses to long-term management of N availability** (2014 - 2015); doi:10.6073/pasta/85328650bd2c757d78f175bdfcf20f70 Top 10 publication: Carson CM, Zeglin LH. 2018. Long-term fire management history affects N-fertilization sensitivity, but not seasonality, of grassland soil microbial communities. Soil Biology and Biochemistry 121:231-239	Zeglin, Lydia; Carson, Christine;	2020	Inorganic Nutrients; Populations	Complete
knb-lter-knz.104.2	**SPR01 Sequential prairie restoration experiment at Konza Prairie** (2010 - 2016); doi:10.6073/pasta/337d465fb5eb7d7144a9b12be0a75952	Baer, Sara; Manning, George	2018	Primary Production	Complete
knb-lter-knz.91.3	**VIR01 Effects of invertebrate and vertebrate herbivory on tallgrass prairie plant community composition and biomass, Konza Prairie LTER** (2009 - 2018); doi:10.6073/pasta/32c8d44870d782a4a94686386c6aeb2d	Komatsu, Kimberly; Smith, Melinda; Joern, Anthony	2019	Primary Production, Disturbance, Populations	Ongoing

knb-lter-knz.72.12	**WAT01 Konza Prairie Long-Term Irrigation Transect Study** (1991 - 2019); doi:10.6073/pasta/f0fd664ab5bc0c68e392cdcec91316a3 Top 10 publication: Komatsu KJ, Avolio ML, Lemoine NP, Isbell F, Grman E, Houseman GR, ... & Anderson JP. 2019. Global change effects on plant communities are magnified by time and the number of global change factors imposed. Proceedings of the National Academy of Sciences, 116(36), 17867-17873	Blair, John	2020	Primary Production, Organic Matter, Populations	Ongoing
knb-lter-knz.138.1	**WRV01 Riparian woody removal vegetation survey on watershed N2B at Konza Prairie** (2010 - 2011); doi:10.6073/pasta/50e8d9598da772c45f5fe25134d0c24b	Dodds, Walter; Carter, Dan; Taylor, Jeffrey	2019	Populations,	Complete