Climate and Biological Response: Research and Applications
Abstracts of selected proposals Updated
(NNH10ZDA001N-BIOCLIM)

The National Aeronautics and Space Administration (NASA) solicited basic research proposals to improve fundamental scientific knowledge of the impacts, in terms of patterns and processes, of climate change on (1) the distribution and/or abundance of species, populations, or functional groups of species and (2) the sustainability over time and/or connectivity of ecosystems across landscapes or seascapes. NASA also solicited applications proposals to enhance the management of populations, species, communities, and ecosystems across landscapes and seascapes of concern through the development or improvement of forecasting tools for resource managers that project the impact of a changing climate on these populations, species, communities, and ecosystems.

NASA conducted this solicitation in concert with the U.S. Geological Survey, the National Park Service, the U.S. Fish and Wildlife Service, and the Smithsonian Institution.

NASA received a total of 151 proposals, and 17 have been selected for funding at this time. The total funding to be provided for these investigations is approximately $18 million over four years.

Helen Bailey/University of Maryland Center for Environmental Science
WhaleWatch: A Tool Using Satellite Telemetry and Remote Sensing Environmental Data to Provide Near Real-Time Predictions of Whale Occurrence in the California Current System to Reduce Anthropogenic Impacts

Many whale populations have been slow to increase in numbers following cessation of commercial whaling, and one of the reasons for this is human-induced mortality. There were 21 blue whale (Balaenoptera musculus) strandings along the California coast during 1988 to 2007, of which 8 were confirmed as ship strikes. Eleven other whale species have been hit by ships, including fin whales (Balaenoptera physalus), humpback whales (Megaptera novaeangliae), and gray whales (Eschrichtius robustus). Entanglement in fishing nets and lines can also lead to drowning, which has resulted in the death of thousands of cetaceans. There is great concern that underwater noise from human sources, such as seismic activity, Navy sonar, vessel noise, and offshore energy can cause stranding, impair hearing, mask calls, or result in area avoidance. These anthropogenic impacts are a major source of mortality to large whales. There is an urgent need for a comprehensive conservation strategy and we propose near real-time predictions of the probability of whale occurrence to help limit anthropogenic activities to times and areas of lower risk to whales. Our team has access to the largest satellite tracking dataset for whales in the world. The advantage of telemetry data is that it provides an animal's eye-view of its movements and habitat preferences, and is not limited to the spatial scale and resolution of standard survey designs. This telemetry data will be combined with satellite-derived oceanographic data to create predictive habitat models. These products will allow large multi-species whale hotspots to be identified, and provide a near real-time tool for determining risk to whales. Managers and users of ecosystem services could identify the time or location at which there would be the lowest probability of whale occurrence, and ultimately the lowest risk to whales. This creates a building block towards developing a decision support system for distribution to marine users, developers, and planners.

The development of our near real-time tool will involve analyzing multi-year satellite-derived tracks of blue, fin, humpback and gray whales in the California Current System. A switching state-space model will be applied to the raw Argos satellite tracks of these whales to provide temporally regularized position estimates and to infer their behaviors. We have already applied this to the blue whale data set, and will apply the same procedure to the fin, humpback and gray whale tracks so that position and behavioral estimates will be comparable for all four species. Satellite-derived environmental data will then be extracted for the time and location of each whale position. This will include sea surface temperature, chlorophyll-a concentration, and sea surface height. Additional variables derived from satellite products will also be used, such as primary productivity, temperature fronts, Ekman upwelling, geostrophic currents, and eddy kinetic energy. We will then use an ensemble of habitat modeling techniques including generalized additive and generalized linear mixed models, and resource selection functions to quantify and predict the probability of whale occurrence based on environmental parameters. The habitat models for each whale species will be calculated from daily to weekly satellite products to generate a near real-time product that predicts large whale occurrence in the California Current System. This tool will be hosted by NOAA/SWFSC and will be transferred to the NOAA Southwest Regional Office. It can then be merged with products describing anthropogenic activities, and developed in the future as a decision support system for managers, the Navy, offshore energy industry, and other marine users to reduce the risk of impact to Federally protected resources such as whales. Our project will support NASA’s objectives by assisting management of marine protected species under a changing climate and facilitating compliance with legal mandates.

Gil Bohrer/The Ohio State University

Type B: Discovering Relationships Between Climate and Animal Migration With New Tools for Linking Animal Movement Tracks With Weather and Land Surface Data

Objectives: We propose to develop a widely needed on-line portal that will streamline the co-registration of animal tracking data with a variety of weather and land surface data. The portal will also provide toolboxes for data visualization and analysis. To ensure relevance and effectiveness, the portal and its toolboxes will be designed in collaboration with wildlife biologists from three federal host agencies: US Fish and Wildlife Service (FWS), US National Parks Service (NPS), and the USGS, and two federal, and private conservation and research institutions: the Smithsonian National Migratory Bird Center (SMBC), and the Acopian Center for Conservation. The portal will provide efficient methods to examine relationships between observed animal movements (time-series of biological observations) and a breadth of information about environmental conditions. The environmental data will be obtained from satellite remote sensing products such as the MODIS ecological, ocean, land cover and land use data sets, as well as from high resolution Digital Elevation Models (DEMs), the NCEP-NCAR weather reanalysis datasets, and datasets from the Study of Environmental Arctic Change (SEARCH). The tools we will provide are useful for studying movement at any scale. Here we will focus our analyses on long distance bird migration, with special attention to arctic birds, since their long-distance movements and rapid changes in the arctic region make them very sensitive to global change.

Perceived significance: Animals are in constant movement across the surface of the earth. Climate affects animals by influencing the way they move through the environment, especially for migrating and flying animals. Understanding animal movement is pivotal to predicting and ensuring the survival of populations in the face of rapid global changes to climate, land-use and habitats. Understanding the mechanisms of animal movement will impart better forecast for the future needs of endangered species and will allow more effective planning for habitat management in national wildlife refuges.
Wildlife migrations are presently tracked using satellite-based systems such as GPS and Argos. With the rapid proliferation of satellite tracking studies, and the exponentially growing availability of information about the Earth's weather and land surface conditions, vast amounts of data are collected that can advance our understanding about the mechanisms that shape wildlife migrations. However, one of the greatest obstacles in conducting such research is the prerequisite task of co-registering the tracking data to the environmental data. The task becomes intractable to most wildlife biologists due to the ominous size of the environmental data sets as well as their unfamiliar formats.
Our infrastructural developments will improve and expand an existing data portal, Movebank (www.Movebank.org). Movebank is a free and sustainable on-line archive of animal movement data, and tools to process it. There are presently >4 million data points from 134 species archived by 273 registered users. The tools we propose will allow Movebank users to directly integrate their animal movement data with remotely sensed earth surface data and weather data. It will also provide tools to extract unique information about weather dependencies of habitat, migration and landscape connectivity in migratory birds and other threatened and endangered species. The USGS, FWS, NPS, SMBC other private organizations are active participants in this project and will contribute observed datasets of bird migration data, as well as participate in the design of the analysis tools, to guarantee their applicability for monitoring and protecting threatened and endangered species.

Robert Crabtree/Yellowstone Ecological Research Center
Ecosystems in Transition: Decision Support Tools to Measure, Monitor and Forecast Climate Impacts on Migratory Species

Ecosystems are in a state of flux due to changing climate. Informed management of species populations and the habitats upon which we all depend confronts us with tremendous and unfamiliar challenges. Migratory species are particularly vulnerable to climate impacts because critical life-history events track environmental conditions across broad regions. Both avian and large mammal migrants are at risk of significant demographic consequences as climatic conditions deviate from historic norms. Making successful management decisions, therefore, will require a detailed understanding of the complex spatial and temporal relationship between climatic, phenological, and landscape

conditions alongside critical life history events. To gain such an understanding, managers require sophisticated yet user-friendly analytical tools and predictive models, as well as datasets that are both spatially-explicit and temporally dynamic such as those provided by remotely sensed data. Thus, the overriding goal of our Type B, Applications proposal is to integrate NASA Earth Science data and data products (including NASA data-driven ecosystem models) into a generalized framework of Decision Support Tools (DSTs) to provide enhanced capabilities for ecosystem and water resource management decisions affecting migratory vertebrate populations. This framework, referred to as the EAGLE (Ecosystem Assessment, Geospatial analysis, and Landscape Evaluation) system, is a response to the input of numerous State and Federal agencies, universities and NGOs. Within EAGLE we link basic science to management decisions by addressing two coupled science application questions (1) How can we predict where migratory species will move during critical life-history stages in response to climate change? (2) What are the demographic consequences of these shifts and movements? To answer these questions and develop a functioning ecosystem monitoring, analysis, and prediction system we build upon the recent cooperative work of our assembled expert team of investigators/collaborators to fulfill three objectives:
(1) Measure, monitor, and analyze the ecological conditions within the species, migration ranges for use in conservation decision-making and predictive modeling by capitalizing on existing, enhanced, and new NASA data products and NASA-data model outputs.
(2) Implement population analyses and predictive modeling of (a) habitat movements (distribution) (b) population vital rates for understanding the effects of climate and climate-related environmental impacts on migrating species. Two of the most extensive, comprehensive, long-term annual wildlife survey efforts in the world “elk in Yellowstone and mallards in the central flyway”are selected for initial analysis and development of the EAGLE system.
(3) Establish a user-friendly, computer-based (web and PC) set of decision-support tools to create species forecasts under habitat what-if-scenarios and IPCC down-scaled climate projections in a user-friendly ArcGIS environment.
Effective adaptation strategies for trust species will require the integration of expert knowledge with accessible state-of-the-art technologies. As such we provide scientists as well as practitioners a standardized, transparent, and defensible set of tools to achieve the management end point of recovering migratory populations while sustaining their habitats. We provide ecological forecasts to assess climate impacts and provide managers the ability to consider strategic habitat conservation, substituting critical space for an uncertain future.

Ilka Feller/Smithsonian Institution
Sensitivity of Coastal Zone Ecosystems to Climate Change

Climate change is fundamentally altering the planet's environment, including increased air and ocean temperatures, melting glaciers and icecaps, and rising sea levels. By altering the environment, climate change is likely to have pervasive but currently unknown impacts on the structure and functioning of ecosystems. Coastal zones are particularly sensitive to climate change given that they are generally within a few feet of sea level. Recent estimates call for a 33% loss of coastal wetlands, including salt marshes and mangroves, by 2080 due to rising sea levels. Coastal wetlands provide crucial ecosystem services, including protection from local flooding, filtration of terrestrial runoff, tourism, and provision of habitat for diverse marine vertebrates and invertebrates that support lucrative fisheries. Nearly 70% of the world's population lives within 50 miles of the shoreline, thus the loss or degradation of wetland services is likely to have substantial impacts on human societies.

Responses to climate change are predicted to be most severe along traditional transitional zones. Thus, we focus on the current and future displacement of temperate cordgrass marshes by eight species of invading mangrove trees from lower latitudes in southeastern North America. Cordgrass marshes are among the world's most productive ecosystems and support ecologically and economically important communities, yet in both North America and worldwide they are rapidly being replaced by tropical and subtropical mangroves. We hypothesize that interactions among increased air and ocean temperatures, rising sea levels, and nutrient over-enrichment are shifting cordgrass marshes to mangrove forests and causing substantial impacts on the structure and functioning of coastal wetlands. Our primary objectives are to: 1) link climatic and biophysical observations to changes in the distribution and composition of salt marsh and mangrove wetlands across spatially variable landscapes; 2) determine impacts on key ecosystem services; and 3) model future distributions of salt marsh and mangrove wetlands.

First, to create historical time-series of mangrove and salt marsh distributions from the 1940's to the present (corresponding with the most rapid increases in global temperature), we will use high resolution aerial photography along with remotely-sensed multispectral high-resolution satellite (IKONOS, QuickBird) and Landsat imagery to recreate historical patterns of shoreline vegetation. In combination with precision GPS surveying of fixed landmarks, we can correlate ecological shifts in wetland vegetation to temperature records, sea level, and environmental disturbance (both anthropogenic and natural). Spatial analysis using GIS tools will also permit development of predictive sea-level rise scenarios (east-west continuum) and ecosystem-replacement scenarios in response to global warming (north-south continuum). Importantly, we will be able to complete remote-sensing analyses wherever mangroves exist worldwide, allowing us to rapidly document global patterns of coastal shoreline transformation.

To determine how mangrove expansion into salt marshes affects ecosystem services, we will conduct faunal and vegetation sampling along a salt marsh-mangrove chronosequence. Standard community statistics will be used in conjunction with stable isotopic analysis to determine differences in food web structure and nutrient dynamics.

Finally, we will combine new data with our existing datasets on mangrove demography to parameterize spatially-explicit, individual-based models (KiWi) simulating the growth, establishment, and death of individual trees for each invading mangrove species. These models will allow us to predict the future structure, composition, and function of mangrove wetlands in a changing climate.

Catherine Graham/Stony Brook University

Combining Remote-Sensing and Biological Data to Predict the Consequences of Climate Change on Hummingbird Diversity

Scientists are challenged to predict how species will respond to continued environmental change in order to mitigate or manage its influences, yet we know little about how the majority of species will respond to these changes. This lack of knowledge limits our ability to predict species responses and manage them in the context of future threats. We propose to combine time-series data for hummingbirds with climate and remote sensing data to evaluate what changes have occurred in hummingbird populations. We will investigate variation in hummingbird resources and hummingbird physiological responses to different environmental conditions to start to determine why these changes might have occurred. Finally, we will predict how species, phylogenetic and functional diversity might be influenced by climate changes. Hummingbirds, a diverse monophyletic family of birds, provide an ideal system for evaluating the effects of environmental changes on biological diversity because birds are highly sensitive to climate and weather and are pioneer indicators of climate change and because as pollinators, their ecology, physiology, and movement patterns are closely related to the distribution, phenology, and abundance of their nectar plants and any change in their nectar availability will directly influence their distributions and abundance.

Integration of coupled time series data sets with species specific biological data to predict how environmental change will influence population persistence requires the use of several different modeling approaches. We will use classical statistical niche models, physiologically informed ecological niche models, Bayesian population models and plant-animal network models to evaluate the relationship between environmental data and biological data and to predict how environmental change will influence population persistence of hummingbirds. Finally, we will collaborate closely with the Hummingbird Monitoring Network and its partners that work in collaboration with the US Forest Service's "Wings Across the Americas" program under the auspices of the Western Hummingbird Partnership. Therefore, we will engage conservation scientists in our research and make our results available for management applications.

In sum, we will address the NASA goals and objectives with respect to Earth science, i.e. to distinguish natural from human-induced causes of change and to understand and predict the consequences of change, as well as the specific objectives of this call. Our proposed research will present an integrated framework of how to link different types of data to predict how environmental change will influence biological diversity. The proposed work has broad societal relevance given the widespread concerns about biodiversity decline with environmental change.

Patrick Halpin/Duke University
Forecasting Climate Change and Its Effect on the Abundance and Distribution of Cetaceans Using Downscaled Output of IPCC Class Earth System Models

Changes in global climate may significantly alter the circulation, biogeophysical processes, and biological productivity of marine ecosystems (IPCC 2007, Hoegh-Guldberg and Bruno 2010). These effects are expected to cascade up from changes in the physical environment to the bio-geophysical systems and then to top ocean predators such as whales and dolphins. The potential impacts of ocean climate change on the range, distribution, and migratory behavior of these apex predators are of significant importance to developing adaptive management strategies for the future. Cetaceans respond to the integrated effects of changing physical and biological processes and act as sentinels for understanding the aggregate effects of broad changes in ocean climate. Our ability to assess their current and future distributions will provide critical baseline information for monitoring aggregate effects of global change.

This proposed project brings together a multidisciplinary team of marine ecologists and climate modelers toconnect changes in physical forcing to changes in top predators. The core of this team is built from an ongoing NASA-ROSES supported collaboration between Duke University and the NOAA Southwest Fisheries Science Center (SWFSC). In this proposal we extend the scope of this work to project cetacean species distributions and habitats under future climate with and expanded team including ocean modelers from NOAA-ERD and NOAA-Geophysical Fluid Dynamics Laboratory (GFDL).
The efforts of our team have already resulted in the development of robust, spatially explicit predictions of cetacean distribution for years with contrasting oceanic conditions (Ferguson et al. 2006; Best et al. 2007; Redfern et al. 2008; Barlow et al. 2009; Becker et al. in press, Schick et al. in review). The most recent models apply remotely sensed and modeled oceanographic data as input variables, allowing hindcasts and short-term forecasts of distribution and abundance for cetacean species, including some endangered whales (Becker et al. in prep). To advance our projection capacity to multi-decadal and centennial scales, we propose to implement such models in the context of output from numerical models simulating the ocean's response to climate change under future scenarios proposed by the Intergovernmental Panel on Climate Change (IPCC).

Our approach is to obtain relevant physical (e.g., SST, thermocline depth, currents, salinity) and biogeochemical (phytoplankton, nitrogen, oxygen) variables from three-dimensional, high-resolution simulations for the regions of interest and forced by IPCC projections as recommended by Stock et al. (in review). Two models from the upcoming IPCC 5th Assessment, developed at GFDL, will provide ocean biogeochemistry and lower trophic level ecological distributions at 1° and ultimately 0.25° resolution (TOPAZ; Dunne et al. 2010). This output will also be used to force a high-resolution (1/12°) physical and biological model (ROMS-CoSINE) for the California Current System, in collaboration with Chavez et al. (pending). Parallel modeling efforts will be conducted on the US Atlantic coast suing the HYCOM modeling framework.

These model outputs will provide input scenarios for models to assess responses of cetaceans to climate variability and characterize biases and uncertainty in these predictions. Potential changes in the distribution patterns of cetacean species will be assessed in relation to current and historical ranges, as available on mapping portals such as OBIS-SEAMAP (Halpin et al. 2009) and the associated Spatial Decision Support

System recently enhanced under NASA funding. Elevated risk will be evaluated based on the level of human use, such as shipping lanes and fisheries, along with management status, such as EEZ boundaries and marine protected areas (MPAs). These analyses will help focus attention to areas of particular need for adaptive management interventions.

Andrew Hansen/Montana State University
Using NASA Resources to Inform Climate and Land Use Adaptation: Ecological Forecasting, Vulnerability Assessment, and Evaluation of Management Options Across Two USDI Landscape Conservation Cooperatives

Designation of US Department of Interior Landscape Conservation Cooperatives (LCCs) emphasizes the important threat that climate and land use change pose to biological resources in national parks and other federal lands. Developing strategies for management and adaptation in the coming century requires improvements in our ability to forecast biological response under future scenarios, assess spatial variation in the vulnerabilities of biological resources, and design multi-scale management strategies based on vulnerability and management feasibility. The goal of this project is to develop and apply decision support tools that use NASA and other data and models to assess vulnerability of ecosystems and species to climate and land use change and evaluate management options. Our objectives are to:
1. Quantify trends in ecological resources from past to present and under projected future climate and land use scenarios using NASA and other data and models across two LCCs.
2. Assess the vulnerability of ecosystems and illustrative species to climate and land use change by quantifying exposure, sensitivity, adaptive capacity, and uncertainty in and around focal national parks within LCCs.
3. Evaluate management options for the more vulnerable ecosystems and species within these focal parks.
4. Design multi-scale management approaches for vulnerable ecosystems and species to illustrate adaptation strategies under climate and land use change.
5. Facilitate technology transfer of data, methods, and models to federal agencies to allow the decision support tools to be applied more broadly.

The proposed work will build on our successful NASA Applied Sciences project to enhance decision support within the National Park Service Inventory and Monitoring Program. This project will focus on portions of the Great Northern and Appalachian LCCs, both of which support critical biological resources and have already undergone climatic warming. Within a climate adaptation framework recently derived by an interagency team, we will integrate component models and data from the Terrestrial Observation and Prediction System (TOPS) and the SERGoM land use change model to hindcast (2001-2010) and forecast (2010-2100) responses of ecosystems and illustrative species to 36 future scenarios. Ecosystem process indicators will include snow pack, runoff, vegetation phenology, primary productivity, lifeform dynamics, and disturbance events. Biodiversity response will be analyzed with a coarse-filter approach emphasizing land facets, ecological system types, and two illustrative animal species. Correspondence among dynamic models of vegetation lifeform and statistical distribution models of ecological system types and dominant plant species will be used to assess uncertainty. The utility of these coarse filter elements for modeling species will be illustrated with analysis of two high priority species: brook trout and wolverine. Results of these forecasts and expert opinion will be used to assess vulnerability and place indicators into one of three management classes: Low Risk (management not needed); Manageable (management effective and required); and Lost Cause (potentially high risk, but management unlikely to mitigate). For those components rated as Manageable, the team will design spatially and temporally-explicit management strategies to improve resilience and/or adaptation. The decision support framework, ecological forecasting tools, and management strategies derived through this project should help to prioritize future activities within the two case-study LCCs and provide a demonstration that may lead to application nationwide. The timing of this project is critical as our NPS collaborations are now developing an implementation plan for the NPS Climate Change Response Strategy. Our proposed approach has already informed the NPS implementation planning and can serve as a case study for NPS Climate Change Adaptation.

Mark Hebblewhite/University of Montana, College of Forestry and Conservation
Global Population Dynamics and Climate Change: Comparing Species-Level Impacts on Two Contrasting Large Mammals

Understanding the effects of climate change on global ecology is a required to predict the effects of climate change on the distribution and abundance of species, and to be able to identify ecosystems and landscapes most at risk to climate change in the future. To date, most approaches to understanding ecological effects of climate change on species have used individual or limited numbers of populations of a species, for example, using Niche modeling, or time-series analysis of individual populations.

While useful, we argue these approaches are fundamentally limited because they do not address species responses at the most appropriate scale for global climate analyses that of the global distribution of a species. Niche models generally predict uniform distributional shifts, but such predictions do not match observations of historic (i.e., Pleistocene) or current species range shifts. This is because they ignore several key components of species responses to climate change; 1) species interactions, 2) spatial/temporal variation in climatic downscaling to local population dynamics, and 3) climate driven synchrony and asynchrony in population dynamics.

Therefore, the goal of our proposal is to use extensive datasets for two contrasting large mammalian species over the entire range of their global and North American distribution to understand the effects of climate change on global scale population dynamics. We call our approach the Global Population Dynamics approach. The main components of the Global Population Dynamics approach are to 1) construct historic and project future environmental niche models based on NASA remotely sensed datasets to evaluate the effect of potential climate change on Elk (Cervus) and Caribou and Reindeer (Rangifer) throughout their circumpolar distribution; 2) evaluate the effects of biotic (i.e., vegetation biomass, predation) and abiotic (i.e, climate) on ungulate population dynamics using time-series of population counts, and 3) understand the degree of spatial synchrony between populations of elk and caribou across global scales and how changes in climate/vegetation synchrony drives population synchrony.

To answer these questions we will use global-scale datasets on the distribution of elk and caribou (broad scale telemetry location datasets), combined with one of the most extensive sets of abundance datasets including >100 time series of these species. We will then address our research objectives by developing niche and time-series population-models using matching spatial-temporal time series of remotely sensed vegetation indices from combined AVHRR-MODIS and MODIS NPP time series (from 1981-the present), MODIS snowcover and landcover, as well as global time series of climate data. Using the MODIS NPP 17A2/A3 dataset will allow us to address the effects of climate itself on ungulates as well as the effects of climate on terrestrial vegetation for the first time. Addressing questions 2 and 3 will then feed back to objective 1 to relax the assumptions of uniform climatic response of species given spatial drivers of asynchrony, and extend the naïve predictions of niche models for these two well studied, but contrasting, species. Finally, we will be able to extend our adjusted Niche model projections to potential future effects of climate change using the most recent CMIP-5 climate model outputs developed for the 5th IPCC assessment. While data-hungry, our Global Population Dynamics approach will set the stage for understanding the challenges of interpreting local-scale climatic analyses for these and other species, and establish a firm understanding of climate change on the distribution and abundance of these two ecologically and economically important species.

Patricia Heglund/USGS-Upper Midwest Environmental Sciences Center
Effects of Extreme Climate Events on Avian Demographics: The Role of Refugia in Mitigating Climate Change

Climate change poses severe threats to biodiversity, and conservationists have to adapt their management decisions to a changing climate. The challenge is that the biological response to future climate change is uncertain. Climate change will entail a general warming, but even more importantly may increase the frequency of extreme climate events (e.g., multiyear droughts) and extreme weather events (e.g., shorter droughts, heatwaves, and cold snaps). Our previous work has shown that extreme events, such as heat waves and droughts affect biodiversity strongly, and can cause strong declines in bird abundances. However, the causes of these abundance declines are not well understood, and at least four mechanisms may be at play.

The first mechanism is lower recruitment, caused either by higher juvenile mortality, or by fewer attempts at reproduction. The second mechanism is adult mortality, which can occur when physiological limits of a species are exceeded during an extreme weather event. The third and forth mechanism are two forms of dispersal, either long-distance dispersal into other parts of a species range (e.g., ducks responding to droughts in the prairie pothole region by migrating to the Boreal to find more favorable breeding conditions), or the concentration of individuals within habitat refugia. Among such habitat refugia, the most important ones are National Wildlife Refuges for waterfowl, and National Forests for forest birds. However, it is not known if these protected areas function as refugia during extreme events. Further, if they do, it is not clear if management actions to enhance food and cover resources could further enhance their role as refugia.

Our proposed study thus has two major goals. The first is a basic science question: we seek to predict the effects of extreme climate and weather events, including droughts, heat waves, and cold snaps during the breeding season, on bird demographics, focusing especially on waterfowl and forest birds. As part of this question we will test four alternative hypotheses to explain observed abundance declines: (1) the lower recruitment hypothesis, (2) the adult mortality hypothesis, (3) the long-distance dispersal hypothesis, and (4) the refugia hypothesis.

Our second goal is an applied research question: we seek to quantify the role of National Wildlife Refuges and National Forests as refugia for waterfowl and forest birds respectively during extreme events, and to identify management actions to enhance this function.

The scope of our work is the conterminous U.S. Our approach will be based on remotely sensed data and in situ wildlife observations. We will use satellite data to map the habitat of bird species and guilds (Landsat, ASTER, and SRTM), and to identify extreme climate events (AVHRR, MODIS, AMSR-E). As biodiversity data, we will use the Monitoring Avian Productivity and Survivorship (MAPS) program, the Breeding Bird Survey, and waterfowl counts from National Wildlife Refuges.

Based on the results of the hypotheses tests, we will simulate population viability, and the role of current and future protected areas for a selection of six species with the metapopulation model RAMAS GIS. The simulation model will quantify the effects of predicted future extreme events on population viability, and help identify optimal management responses.

Our proposed work will make a substantial contribution to both biodiversity science and to conservation. In terms of the NASA Earth Science research objectives, our project examines how the earth system is changing, how the earth system responds to natural and human-induced changes, and how the earth system will change in the future. We will make strong use of NASA assets since it will be based on, and revolve around, satellite data. Last but not least, the project will have broad societal relevance given widespread concerns about biodiversity declines, and improve broad-scale conservation efforts.

Elizabeth Holmes/NOAA Fisheries
Forecasting Changes in Habitat Use by Bowhead Whales in Response to Arctic Climate Change

The effects of climate change are projected to be disproportionately pronounced in polar regions, where changes in the density and extent of sea ice will have pronounced effects on the spatio-temporal dynamics of the marine planktonic ecosystem. The endangered bowhead whale (Balaena mysticetus) is one of the largest animals in the Arctic, yet they feed on some of the smallest Arctic animals, zooplankton. Changes the abundance and distribution of zooplankton due to changes in sea ice would have direct effects on bowhead whales. In addition, loss of Arctic sea ice also has the potential to increase negative anthropogenic interactions, as areas become more accessible to vessels and oil exploration. The proposed work brings together a multidisciplinary team with expertise in biogeochemistry and climate modeling of the Arctic, baleen whale distribution modeling, bowhead whale biology and habitat, and the effects of climate change on Arctic marine mammal biodiversity and conservation. Working together, our objective is to improve understanding of how the Arctic planktonic ecosystem affects the regional distribution of bowhead whales and to develop forecasts of long-term changes in their distribution under different Arctic climate change scenarios.

Our proposed work builds upon a forecasting system developed for a similar baleen whale species, the North Atlantic right whale (Eubalaena glacialis) (Pendleton 2010, Pendleton et. al. 2009, Pershing et al. 2009, Pershing et al. 2009). This system, developed with funding from the NASA Applied Sciences program, generated weekly predictions, at regional and local spatial scales, of right whale habitat quality. Environmental niche models (ENMs) integrated satellite-derived SST and chlorophyll, modeled zooplankton abundance, bathymetry, and aerial and acoustic detections of whales to produce habitat maps with good predictive accuracy (Pendleton et. al. 2009). The ENMs were used to evaluate shipping lanes in order to reduce whale-vessel collisions, a primary threat to right whales.

We propose to extend this approach for bowhead whales in the Chukchi-Beaufort Seas (CBS) using output from a NASA-supported project: The pan-Arctic Biology/Ice/Ocean Modeling and Assimilation System (BIOMAS), PI: J. Zhang. BIOMAS is a fully coupled 3D biology/sea ice/ocean model with an 11-component lower-trophic model adapted to the Arctic Ocean. BIOMAS generates hourly estimates of three zooplankton components (microzooplankton, mesozooplankton/copepods, and predatory zooplankton), from 1988 to present at a resolution of 4-10km (for the Bering, Chukchi, Beaufort subdomain). Our work will use BIOMAS output to develop habitat suitability models for bowhead whales in the CBS. To do this, ENMs using the BIOMAS output along with satellite time series data on SST, sea-ice and chlorophyll will be trained with a 30+ year time series of bowhead sighting data from aerial surveys in the CBS. Two types of ENM techniques will be used, boosted regression trees and maximum entropy density estimation. Using these ENMs, we will explore changes in bowhead whale habitat suitability in the CBS under different climate change scenarios. BIOMAS will be used to develop forecasts of the spatio-temporal distribution of zooplankton under different IPCC Arctic climate change scenarios. These zooplankton forecasts will then be used to drive the ENMs. This type of scenario study will help us understand the potential changes in bowhead whale distribution and help evaluate strategies for minimizing human-whale interactions as sea-ice extent and whale populations change in the coming decades.

Walter Jetz/Yale University

Integrating Global Species Distributions, Remote Sensing Information and Climate Station Data to Assess Recent Biodiversity Response to Climate Change

Global insights into the magnitude of the biotic response to climatic change are desperately needed. It is therefore imperative to make full use of all available biodiversity distribution data over the broadest possible spatial and temporal extents. Earlier efforts at linking climate variability and changes to biological responses suffer from a lack of spatially and temporally consistent environmental data layers. The proposed project is able to build on existing collaborative efforts and initiatives to address this need. Specifically, the project has four objectives:

1) Layer development. We will apply TOPS to produce global biophysical data layers derived from MODIS, Landsat, and observations from the global network of surface meteorological stations. In addition, we will use a novel approach to fuse MODIS data and climate station information to develop global layers of precipitation and temperature at a monthly 1km resolution, extending from 1971 to 2010. The fusion of spatially continuous satellite data and meteorological station data, as opposed to statistical interpolation techniques alone, will yield layers that allow more rigorous change assessment and species distribution modeling, especially in areas where biodiversity is the highest (e.g. the tropics). For 3-4 periods we will also derive 10-class continuous land cover dataset at a 1km resolution from a fusion of Landsat and MODIS for land cover change assessment.

2) Remote-sensing data based species distribution modeling. First we will use the remotely sensed layers developed in Objective 1 to provide temporally precise environmental annotations to biodiversity point occurrence data (focus: terrestrial vertebrates) made available in large quantities through services such as GBIF and VertNet. These annotated records can then be used to model species ecological niches and distributions using well established methods. We will compare the relative performance of satellite data to fused layers and to interpolated layers for successfully capturing species distributions.

3) Changes in species geographic and environmental distributions 1971-2010. After selecting and quality-controlling species with sufficient data in GBIF/VertNet, we will perform a geographic range and environmental niche assessment for > 1000 focal species drawn from many regions of the world. We will determine how these species' niches and ranges have varied in relation to climatic changes over two 20-year time periods (1971-1990 and 1991-2010) using the monthly 1km fused data layers produced in Objective 1. The final out will be an assessment of the magnitude, geographic and taxonomic variation in species responses to recent climate change.

4) Change in environment and focal species occurrences in reserves for 1971-2010. For a global selection of protected areas and all SIGEO sites we will first assess the magnitude of observed climatic changes within these reserve utilizing new remote sense layers. Second, we will compare changes in the distribution of focal species predicted to occur in those reserves between the two twenty year time periods to create a scorecard showing climatic impacts on these areas.

The proposed project offers tremendous synergies with existing global biodiversity efforts and will add a vital environmental change and remote sensing dimension to them, thus strongly advancing the contribution of NASA to the biodiversity community. Its goals are strongly aligned with the high-priority research tasks of the Group on Earth Observations Biodiversity Observation Network (GEO BON). The project outcomes of production, analysis, and distribution of global environmental data layers, enriched biodiversity information, probabilistic reserve species lists and biological change assessments will improve scientific knowledge and facilitate natural resource management in multiple significant ways. All products and metadata will be freely distributed in interoperable formats.

Kristin Laidre/University of Washington
Climate Change, Sea Ice Loss, and Polar Bears in Greenland

Loss of sea ice has had extensive and severe population-level impacts on polar bears (Ursus maritimus) across the Arctic because polar bears require sea ice as a platform on which to hunt ice seals. These impacts include declines in body condition, survival, and population size and an increasing trend of polar bears on land during summer. Little is known about the effect of climate change on the polar bears that inhabit East and West Greenland, regions that have exhibited some of the highest rates of annual sea ice loss (9-10% per decade) in the Arctic. The proposed work will aim to understand and quantify the effects of sea ice loss on polar bears in East and West Greenland (Baffin Bay). Longitudinal (cross-time) comparisons of movement behavior and habitat selection will be driven by an analysis of a multi-decadal satellite telemetry dataset on polar bear movements in Baffin Bay and East Greenland, beginning when sea ice concentration and break up date started to decline (1991-1997) and encompassing present day conditions (2007-2013). Satellite telemetry data will be analyzed together with environmental covariates and climate observations, in particular those related to sea ice coverage, concentration, location of the sea ice edge, and date of spring break-up and autumn freeze-up (SSM/I and AMSR-E). A suite of spatial ecological models will provide an informative perspective on how sea ice loss in Greenland has impacted polar bear behavior. We propose to develop on-ice and on-land resource selection models and behavioral movement models for bears of different sex, age class, and reproductive status and quantify and contrast how these two populations are adapting to sea ice loss. We will identify key focal areas for polar bears and quantify how sea ice habitat in these regions has changed over a 30+ year time period. Polar bears in East Greenland occupy a convergent ice ecoregion (remain on the annual and multi-annual pack ice if possible) while polar bears in West Greenland occupy a seasonal ice ecoregion (spend up to 3 months on land fasting during summer), thus we will also be able to make cross-population comparisons contrasting two ecoregions with similar sea ice loss rates. The biological dataset for this proposed work includes n=107 individual polar bears fitted with satellite-linked radio transmitters and tracked over 3 annual cycles between 1991 and 2013 in East Greenland (n=30) and West Greenland (n=77). One additional year of tagging in West Greenland in spring 2011 will raise the sample size by approximately n=20 polar bears transmitting through 2013. Information on shifts in polar bear habitat use, fasting and on-ice feeding periods is vital for the assessment, monitoring, and conservation in the face of climate change. One of the populations in our study (Baffin Bay) was identified to be of international concern by the IUCN (International Union for the Conservation of Nature) Polar Bear Specialist Group in July 2009 partially due to large-scale habitat loss. Our proposed study includes all three key criteria for this announcement: 1) a long-term time series of existing and relevant climate observations

(SSM/I and AMSR-E sea ice data), 2) a long-term time series of biological observations on the distribution of species or populations (a 20+ year time series of polar bear movements from two separate populations), and 3) spatially-explicit ecological models that facilitate the understanding of the influence of climate change on biological systems. This iconic species is not only the subject of broad public interest but also an important subsistence resource to indigenous people. The results will be vital for conservation decisions given increasing human activities due to Arctic climate change such as increased shipping and oil exploration and drilling on both coasts of Greenland.

David Mattson/USGS Colorado Plateau Research Station
Spatial Responses to Climate Across Trophic Levels: Monitoring and Modeling Plants, Prey, and Predators in the Intermountain Western United States

We propose to investigate the impact of climate on trophic linkages between primary productivity, herbivores, and top predators across landscapes in the western United States. This research will generate new understandings of climatic influences on vegetation, foraging, and animal movement, and will produce quantitative recommendations for the management of public lands. Using the NLCD 2001 and MODIS land cover to distinguish vegetation types and MODIS 16-day NDVI composites to measure plant development, we will model land surface phenology based on geospatial climate datasets, including interpolated, remotely sensed, and topo-climatic variables derived from digital elevation models. We will deploy GPS collars on 30 mule deer and use the data collected to model spatial patterns of ungulate density on a 16-day interval based on remotely sensed phenology. The resulting approximately semi-monthly dynamic ungulate habitat models will be used to extrapolate predictions of prey density across the study area, which we will then use as the main predictor for modeling cougar movement using a decade of records collected from 70 intensely monitored individuals across the region. Once fit to data, the movement models will be simulated using Monte Carlo methods to predict the habitat occupancy and traversibility over the study area for cougars. Resulting occupancy surfaces will be modified by spatially-explicit estimates of survival from known fates of >200 cougars to derive analogs of density. With the cost and occupancy surfaces from this analysis, we will then analyze the habitat and movement of cougars as a network to assess the sustainability of the regional cougar metapopulation.

The proposed research is of Type A (basic research). The study will fit niche-based distribution and animal movement models to remotely sensed data in order to describe the linkages between climate and ecosystems across the three dominant trophic levels (i.e., primary producer, herbivore, and predator), and will be the first study to do so at such an expansive scale. The research will gather time series of satellite images and coincident direct measurements of predator-prey communities over nearly a decade, as well as static soil, topography, and other geospatial data layers into a model ecosystem to inform natural resource management across the region. It will thus improve fundamental and applied scientific knowledge of the distribution and abundance of species and the connectivity of metapopulations, as governed by climate. Although not directly targeted at ecosystem management as a Type B proposal, the study has clear implications for managing wildlife populations in the face of climate change.

Jeffrey Morisette/USGS Fort Collins Science Center
Using the USGS "Resource for Advanced Modeling" to Connect Climate Drivers to Biological Responses

The USGS Fort Collins Science Center has established both the expertise to create state-of-the-art near-term climate-based habitat models and the infrastructure to connect these urgent modeling results on species of greatest concern to land managers.

Meanwhile:
- NASA continues to make improvements and enhancements to the satellite-derived products that the USGS is using for predictor layers in its habitat modeling,
- Computing speed is available through NASA to allow much more exploration of modeling parameters and climate or land use scenarios, and
- NSF- and DOE-sponsored workflow management and scientific visualization software is available to help interpret and manage the results of multiple and complex model exploration and iteration.

Here we propose an effort to improve the USGS's "Resource for Advanced Modeling", that will serve DOI habitat modeling needs by bringing USGS and NASA resources together in a distributed modeling system that maximizes the complementary strengths of both NASA and the USGS.

To demonstrate the utility of this capacity the project will focus on both: invasive species and threatened and endangered species; two critical land management issues. The proposal is a hybrid; combining technical capacity with a natural resource applications focus.

Mitchell Roffer/Roffer's Ocean Fishing Forecasting Service, Inc.
Management and Conservation of Atlantic Bluefin Tuna (Thunnus thynnus) and Other Highly Migratory Fish in the Gulf of Mexico under IPCC Climate Change Scenarios: A Study Using Regional Climate and Habitat Models.

This "applications" research project focuses on enhancing the management of multiple important highly migratory pelagic fish species in the Gulf of Mexico and surrounding waters, with particular focus on Atlantic bluefin tuna (Thunnus thynnus) and other highly migratory tunas and billfishes. Our team has developed an innovative spawning habitat model for Atlantic bluefin tuna in the Gulf of Mexico in a collaboration with the National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NOAA NMFS). The study proposed will leverage our present collaborations to project this habitat model into the future using IPCC climate models and scenarios to assess possible effects of climate change on the spawning habitat and fish population dynamics.

We will improve the present habitat model by incorporating a 28-year time series of NOAA NMFS SEAMAP ichthyoplankton surveys in the Gulf of Mexico, historical fisheries analyses (commercial pelagic longline fishing observer data) in the Gulf of Mexico, and relevant historical oceanographic data including historical and concurrent satellite imagery. Specifically, we will assess the habitat using the numerical simulations constructed for the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC AR4), which are being refined in preparation for the fifth assessment report (IPCC AR5). We will apply the model results both for the North Atlantic and in a downscaled mode, using HyCOM and ROMS modeling to assess scenarios within the Gulf of Mexico.

The research is important because strives to develop functional links between climate variability, regional-scale oceanographic processes, and fisheries recruitment. The Atlantic bluefin tuna and other highly migratory fish species that use the Gulf of Mexico as essential habitat are still largely managed under the assumption that ecosystem parameters do not change over time. At the moment, how possible climate scenarios may affect these fish populations under other varying human pressures is unknown.

The research team is multi-sector and multi-disciplinary, including government fishery experts and managers (NOAA NMFS Southeast Fisheries Science Center), government satellite researchers (NOAA OAR AOML), academic (University of Miami Cooperative Institute of Marine and Atmospheric Sciences and University of South Florida Institute for Marine Remote Sensing) and commercial (Roffer's Ocean Fishing Forecasting Service, Inc.) partners. This collaboration brings together time series of climate observations from satellite and in situ data, time series of biological observations, and ecological and climate models.

Richard Waring/Oregon State University, College of Forestry
Mapping of Stress on Native Tree Species Across the Western United States and Canada: Interpretation of Climatically-induced Changes Using a Physiologically-Based Approach

Fly across the western United States and Canada and you will be struck by the size of areas where forests are dying or are aflame. Over the last 30 years, the climate in the West has become progressively warmer and drier but the implications of these changes on vegetation are not well understood. We have developed physiologically-based models that accurately predict the presence of more than a dozen tree species on thousands of field survey plots distributed across the Pacific Northwest Region of North America, when calibrated using climatic records for the period 1950-1975. When the models are run with more recent climatic data, they indicate large areas are no longer suitable for many species, and the future, based on climatic projections through the rest of this century, look even bleaker. Although satellite-borne instruments can help us quantify annual changes in forest cover, they are unable to explain why the changes are occurring or the extent that they may continue. The forested areas that satellites tell us were recently disturbed, however, correlate very well with the areas predicted as stressed with our models.
In this grant proposal, we request support to extend the approach used in the Pacific Northwest to the entire Rocky Mountain West, including parts of the Canadian providences of Alberta and Saskatchewan where drought is acknowledged to be causing shifts in the distribution of native tree species. We propose to increase the number of

species modeled to twenty-five, which will include the most widely observed dying species: piñon pine, lodgepole pine, and aspen. We will compare model predictions of species mortality and migration outside of their historical ranges using ground-based observations acquired by collaborators throughout western North America.

The benefits to NASA of this proposed research are that we can offer an explanation as to why species may be dying, use a disturbance index developed from data acquired with NASAs MODIS instrument to test model predictions of where forests are under stress, and enlist collaborators to visit sites where climate-driven models suggest changes in forest composition are most likely to be observed. We propose to share the results of the research with representatives of the U.S. Forest Service, NASA Ames Research Center, the National Park Service, the Department of Energy, the Nature Conservancy as well as with colleagues at participating universities.

David Wethey/University of South Carolina

Physiological Impacts of Climate Change Using Remote Sensing: An Integrative Approach to Predicting Patterns of Species Abundance and Distribution and Thresholds of Ecosystem Collapse

This proposal builds upon our previous NASA-sponsored research where we developed biophysical heat budget models to successfully predict the body temperatures of marine organisms using NASA remote sensing products as data inputs. Like most other approaches to exploring the determinants of current and future species range boundaries, our prior research focused largely the role of lethal limits. However, recent studies have emphasized that understanding sublethal patterns of environmental stressors may play a key role in understanding the ecological effects of climate change. First, some species may be □close to the edge□ al changes in temperature may lead to large changes in distribution. Second, recent studies have shown that range limits are not always set by short-duration, lethal exposures, but instead by more chronic exposures that lead to irreversible physiological damage. Predicting the likely ecological impacts of climate change demands that we move beyond the role of lethal limits in setting species range boundaries. The use of NASA Remote Sensing products to predict global patterns and changes of animal body temperature, through a combination of biophysical and physiological models allows an unprecedented opportunity to forecast changes in physiological performance within the current and future geographic ranges of the major constituents of coastal marine ecosystems. Our modeling approach is flexible, allowing future developments in remote sensing technologies and regional or global climate modeling to be rapidly incorporated. Finally and importantly, we base our approach on a general model of the effects of body temperature on physiological performance and tolerance that is applicable to virtually any organism in any habitat and thus we anticipate our results to have wide application in developing approaches to forecasting biological responses to changing climate. Our proposed research is focused on the following questions. All are independent of specific system i.e. the results and approach are generally applicable. Are models validated for one geographic region or time period applicable to all other regions of the species □ range, and are they temporally invariant? A fundamental assumption of most climate change research is that determinants of range boundaries can be extrapolated in space and time; yet, our results suggest that such stationarity or niche conservatism may be false. Can we predict when models of species geographic distributions will fail when extended to other spatial or temporal domains? We predict that models of distribution will frequently fail if the species has physiological performance curves suggestive of significant thermal stress well before the species lethal thermal limit. Does a combination of time-integrated performance metrics such as productivity with thermal lethal limits increase the success of models validated through hindcasts and nowcasts in one geographic region when extended to other spatial and temporal domains? We will test this prediction using bivalve species, particularly those of commercial interest. Datasets of distribution and abundance for over one hundred years are available with which to test this prediction through hindcasts and nowcasts from our body temperature models based on NASA R/S products.