Cover Page for Proposal Submitted to the National Aeronautics and Space Administration

NASA Proposal Number

20-EARTH20-0139

NASA PROCEDURE FOR HANDLING PROPOSALS

This proposal shall be used and disclosed for evaluation purposes only, and a copy of this Government notice shall be applied to any reproduction or abstract thereof. Any authorized restrictive notices that the submitter places on this proposal shall also be strictly complied with. Disclosure of this proposal for any reason outside the Government evaluation purposes shall be made only to the extent authorized by the Government.

SECTION I - Proposal Information

Principal Investigator	E-mail Address	Phone Number
Volker Radeloff	**radeloff@wisc.edu**	**608-263-4349**

Street Address (1)	Street Address (2)
1630 Linden Dr	

City	State / Province	Postal Code	Country Code
Madison	**WI**	**53706-1520**	**US**

Proposal Title : **Agricultural abandonment across the Eurasian steppe: effect on fires, vegetation succession and habitat quality for rare waterfowl species**

Proposed Start Date	Proposed End Date	Total Budget	Year 1 Budget	Year 2 Budget	Year 3 Budget
09 / 01 / 2021	**08 / 31 / 2024**	**135,000.00**	**45,000.00**	**45,000.00**	**45,000.00**

SECTION II - Application Information

NASA Program Announcement Number	NASA Program Announcement Title
NNH20ZDA001N-FINESST	**E.5 Future Investigators in NASA Earth and Space Science and Technology**

For Consideration By NASA Organization *(the soliciting organization, or the organization to which an unsolicited proposal is submitted)*

NASA , Headquarters , Science Mission Directorate

Date Submitted	Submission Method	Grants.gov Application Identifier	Applicant Proposal Identifier
02 / 04 / 2021	**Electronic Submission Only**		

Type of Application	Predecessor Award Number	Other Federal Agencies to Which Proposal Has Been Submitted
New		

International Participation	Type of International Participation
No	

SECTION III - Submitting Organization Information

DUNS Number	CAGE Code	Employer Identification Number (EIN or TIN)	Organization Type
161202122	**09FZ2**		**2A**

Organization Name (Standard/Legal Name)	Company Division
University Of Wisconsin, Madison	**RESEARCH & SPONSORED PROGRAMS**

Organization DBA Name	Division Number
RESEARCH AND SPONSORED PROGRAMS	

Street Address (1)	Street Address (2)
21 N PARK ST STE 6401	

City	State / Province	Postal Code	Country Code
MADISON	**WI**	**53715**	**USA**

SECTION IV - Proposal Point of Contact Information

Name	Email Address	Phone Number
Volker Radeloff	**radeloff@wisc.edu**	**608-263-4349**

SECTION V - Certification and Authorization

Certification of Compliance with Applicable Executive Orders and U.S. Code

By submitting the proposal identified in the Cover Sheet/Proposal Summary in response to this Research Announcement, the Authorizing Official of the proposing organization (or the individual proposer if there is no proposing organization) as identified below:

- certifies that the statements made in this proposal are true and complete to the best of his/her knowledge;
- agrees to accept the obligations to comply with NASA award terms and conditions if an award is made as a result of this proposal; and
- confirms compliance with all provisions, rules, and stipulations set forth in this solicitation.

Willful provision of false information in this proposal and/or its supporting documents, or in reports required under an ensuing award, is a criminal offense (U.S. Code, Title 18, Section 1001).

Authorized Organizational Representative (AOR) Name	AOR E-mail Address	Phone Number
Darlene Holte	**johnsonholte@rsp.wisc.edu**	**608-890-3509**

Table of Contents

Personal Statement

I believe that human activities are a major trigger for many long-term biological processes, however many of them still remain undiscovered. The Eurasian steppe plays a vital role for biodiversity not only for grassland species but for many migratory species such as Arctic breeding birds. At the same time the steppe is a broad-scale "natural experiment" of rapid human-made land cover changes. Last but not least, grasslands are a highly transformed landscape across the globe and in need of conservation efforts.

My overall scientific interest is to combine remote sensing data with other modern technologies for biological research and nature conservation. In the proposed FINESST project I am planning to conduct interdisciplinary research that applies Landsat data for land use, botanical and zoological studies in the Eurasian steppe. I will study how land use changes trigger fire dynamics and vegetation succession, and affect plant biodiversity and the ecology of rare waterfowl. A FINESST grand would allow me to scale up and intensify my research to achieve most notable scientific results with many practical applications. I will analyze all Landsat 4-8 imagery to create maps of fire dynamics, and conduct extensive fieldwork in Kazakhstan to collect the necessary *in situ* data.

A major potential barrier in the project might arise from fieldwork difficulties due to the COVID pandemics, as well as weather and other unpredictable factors. To mitigate this risk, I am planning to conduct all the fieldwork during the first year of the project (spring of 2022), but I could also conduct my field work in the second year. Different parts of the research are independent and could be replaced in the proposed schedule if the fieldwork has to be done in 2023. If any difficulties appear in statistical analysis or modeling, I will consult with statisticians in the CALS Statistical Consulting lab (https://stat.wisc.edu/statistical-consulting-lab-cals/).

Previous experience

I received my MS degree from the biological faculty of Lomonosov Moscow State University, the highest-ranked university in Russia. I have a deep botanical, zoological and ecological background as well as knowledge in GIS and species distribution modeling. While working on my MS, I studied distribution of small falcons in the Russian steppe regions in relation to human-triggered land cover changes.

Having graduated with my MS from Lomonosov Moscow State University, I decided to combine GIS, research, and conservation as closely as possible in my further employment. I was lucky to take part in several international and national projects where I worked as both a GIS specialist and a biologist. Among those were projects that mapped forests of high conservation value in the Caucasus, Northern Russia, and the Russian Far East. Besides, I led fire monitoring in national protected areas for the Ministry of Natural Resources of the Russian Federation. The most extensive project I have taken part in was the Steppe Project of UNDP/GEF where I was in charge of producing steppe maps for southern part of European Russia. The work required analysis of land use in the steppe zone for the last 50 years using Landsat and Corona archives. In addition to the steppe maps, the results of my work included novel methods to better separate different types of natural grasslands as well as arable and abandoned fields, old and fresh pastures etc.

Due to my scientific interests in zoology, I joined a research team studying Arctic waterfowl. This work included combining satellite images with bird's movement data from GPS trackers. Using all this, I created maps of habitats, revealed nesting sites and migration stopovers in arctic Russia, assessed bird numbers and their distribution across the breeding area.

Almost all these projects included a lot of field work. I believe that good ecologists must know their objects from a long-term field experience and understand natural processes from direct observations. This is why I have worked as much as possible in the wild across Russia to collect the necessary ground data and verify my maps.

Another part of my life have been volunteer activities connected to nature conservation. Since my first university years I joined to a volunteer firefighter group. We started with defending a state natural park where uncontrolled fires were a real challenge every year, and became more experienced as we worked in many of Russian natural protected areas. This activity gave me a lot of firefighting practice as well as an understanding of real scale of uncontrolled fires in Russia and their consequences for nature.

In 2018 I decided to return to academia science and started as a PhD student and a research assistant in the SILVIS lab at the Forestry Department in UW-Madison. As a student I focused on courses in statistic and R programming, and how to use Google Earth Engine for analysis of remote sensing data. As a research assistant I have been working on Professors Radeloff's NASA MuSLI project, contributed to the development Google Earth Engine algorithm for mapping abandoned crops. Our results were published in "Remote Sensing of Environment" (Yin et al., 2020, RSE, 246: 111873). Based on this algorithm I developed land cover and land use change maps for Kazakhstan and parts of Russia, that Prof. Radeloff presented at the NASA LCLUC Virtual Science Team Meeting in October, 2020. In order to collect ground data for verification of this map I conducted an extensive fieldwork in summer 2019 in Russian Siberia and collected more than 5,000 points of abandoned fields and different grassland vegetation. I am now fine-tuning the classifications, especially in the most arid part of my study area, and finalize the accuracy assessment, and I will submit a manuscript describing these analyses in the summer of 2021.

Apart of the science I am developing myself as a wildlife photographer. When small unmanned aircraft became available, I started using them for photography and wildlife observation in addition to more conventional equipment. Now I own a small drone equipped with a precision camera. I am also an off-road driving fan, and I have gained a lot of experience doing so during my firefighter activity, previous fieldwork and photo-travels. I hope all the skills are helpful for my current and future research.

Passed and anticipated milestones of my PhD degree program are:

PhD Start date:	September, 2018
Prelim:	April, 2020
Finish coursework:	May, 2020
Expected PhD completion date:	August, 2024

Cumulative GPA: 3.895

Science/Technical/Management Section

Agricultural abandonment across the Eurasian steppe: effect on fires, vegetation succession and habitat quality for rare waterfowl species

Introduction

The Eurasian steppe has undergone two vast conversions in the second half of the 20th century: a massive expansion of agriculture (the 'Virgin land' campaign in the 1950-1960s) and a widespread agricultural abandonment after the collapse of the USSR. This abandonment has resulted in the increase in burned area (1, 2), revegetation of former fields with steppe plant communities (3, 4), and changes in migration routes of Arctic breeding birds (5).

The substantial increase of burned area has especially strong environmental consequences such as a rise in carbon emission, change in vegetation structure, and threats for human lives and property. Furthermore, there could be a positive feedback loop in that fires foster successional pathways in favor of more flammable communities, resulting in even more fires (6). However, fire dynamics and their effects on vegetation have been studied only for the central Kazakhstan and Kalmykia (6, 7), and it is unclear how fires and vegetation have change in other parts of the Eurasian steppe.

Environmental changes along migration corridors greatly affects population numbers of Arctic breeding geese (8). The Eurasian steppe attracts millions of migratory birds, including several rare and endemic species (9, 10). The expansion of agriculture created a new source of food for the birds, and cropland abandonment removed that. The question is how the changes in land use have affect migratory species, which is important for bird population management and rare species conservation.

Remote sensing data is a highly effective tool to monitor land cover and land use changes, fire dynamics and wildlife habitats for large areas. The Landsat program of NASA/USGS provides a wall-to-wall coverage of 30-m resolution satellite images since the early 1980s. Combining Landsat data with drone imagery and GPS-trackers capturing bird movements will allow me to study large-scale ecological changes.

The purpose of my research is to study the effects of agricultural abandonment in the Eurasian steppe on fires, vegetation successions, and habitat use by rare migratory geese

My specific objectives are:

1. To understand fire dynamics since the late Soviet period in unplowed steppes and abandoned fields in order to reveal relationships between fires and land use changes.
2. To estimate vegetation succession in relations to fires in unplowed steppe and on abandoned fields.
3. To analyze habitat usage by rare waterfowl species, the spatial-temporal variability of their stopover sites, the role of land cover changes in this variability, and to model bird distribution in Eurasian steppe during migrations.

My research addresses the NASA Earth Science Research program goal entitled «Detect and predict changes in Earth’s ecosystems and biogeochemical cycles, including land cover, biodiversity, and the global carbon cycle”, particularly the Earth Science focus area of “Ecosystem change”. My results will advance land change science by revealing long-term fire dynamics in natural and formerly plowed grassland communities thus providing new insights into the interactions of land use and fires. My botanical and zoological research questions will assess ecological changes and habitat dynamics in steppe communities, and their consequences for biodiversity and rare species.

Study area

My study area (2,600,000 km^2), covers the western part of Eurasian steppe zone (Fig. 1). In Russia, steppe remains east of the Volga River and along the Russian-Kazakh border. In Kazakhstan, steppe is still widespread despite their massive conversion to arable fields during the Soviet time. The climate varies from humid-continental to cold arid (11); the soils are chernozems in the north, light kastanozems in the middle, and gray-brown arid formations in the south; the vegetation is represented by a wide range of grasslands from meadow-steppe to shrubby deserts (12, 13). The northeast part has numerous lakes, which attract large flocks of waterfowl during their migrations.

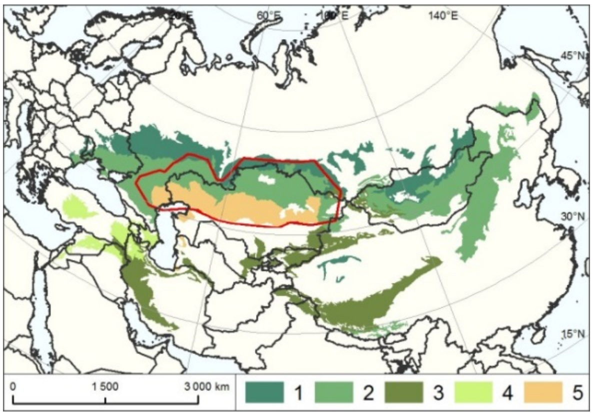

Fig 1. Eurasian steppes.1-forest-steppe, 2-steppe, 3-mountain steppe, 4-enclaves, 5-steppe-desert. Study area is shown in red

As a graduate student in a current NASA MuSLI project (PI V. Radeloff), I have already developed a set of annual land cover maps dated from 1988 to 2018 and delineated land use changes over the whole study period (Fig. 2).

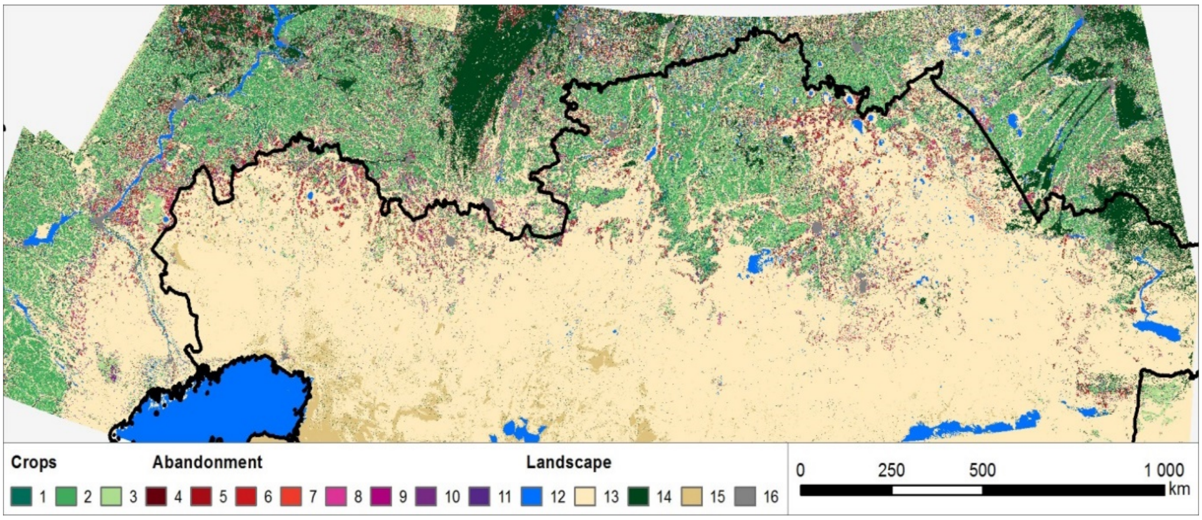

Fig 2. Land cover and land abandonment map. Crops: 1- recultivated, 2- stable, 3- fallows; abandonment: 4-1992-1994, 5-1995-1997, 6-1998-2000, 7-2001-2003, 8-2004-2006, 9-2007-2009, 10-2010-2012, 11-2013-2015; landscapes: 12-water, 13-grasslands, 14-forest, 15-bare ground, 16-settlements

The maps show active agricultural land use in the north and the west where soil and weather conditions are the most favorable. Abandonment is more common further south, and the southern-most part is almost totally depopulated. The work proposed for the FINESST program will build on my prior work, but none of the proposed work here is part of the MuSLI project, which is almost completed and will end on 1/14/22; so there is no overlap.

Approach

Objective 1: Fire dynamics from the late Soviet period to present in unplowed steppes and abandoned crops and the relationship between fires and land use changes

Fires are common in grasslands around the world, including the Eurasian steppe. However, fire frequency and extent in this region has increased substantially since the late 1990s, i.e., following the peak of abandonment. Fuel accumulation on abandoned lands may have caused these changes, but evidence for that is restricted to few case-studies (1, 2, 14). In the most of Eurasian steppe, especially in its relatively undisturbed parts, fire dynamics are unknown.

I hypothesize that fire frequency and burned area have evenly increased throughout the Eurasian steppe, both in unplowed grasslands and in abandoned fields. To test this hypothesis, I will develop annual fire maps for the whole study area and evaluate temporal fire regimes changes in unplowed steppe and in the abandoned fields for each ecoregion (from forest-steppes, to dry steppes and semi deserts). For the mapping I will use Landsat images from 1986 to 2020 complemented by MODIS data where Landsat coverage is insufficient.

I will collect a set of points in burned and unburned sites in both natural steppe and abandoned areas for each year and randomly divide them into two parts: training and verification (2). Although the best practice of point collection is using satellite images with higher spatial resolution, I will have to complement this with visual interpretation of Landsat images (15) because, in fact, there is no other remote sensing data covering all years across the study area. To check the quality of my visual interpretation I created several preliminary fire maps based only on visual Landsat interpretation and compared them with the other automatic classifications (made in Kalmykia by M. Dubinin 2010 (16); see Fig 3) and ground data (114 GPS-mapped fire scars from my field work in 2019). With Landsat images, the overall accuracy of my visual interpretation was around 97%, which proved this approach as fully reliable.

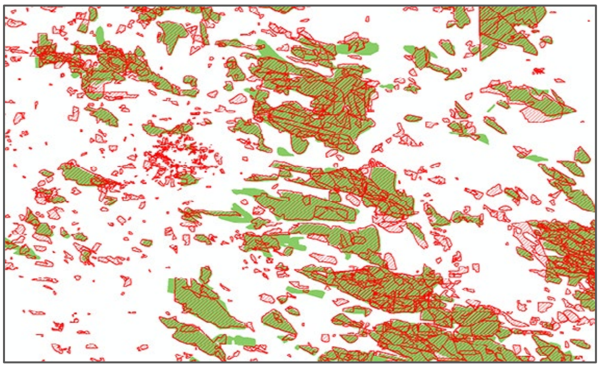

Fig 3. Comparison of visual Landsat interpretation and MODIS-based automatic classification. MODIS map is shown in green; Landsat map in red

In my classifications, I will test which indices (such as Normalized Burned Ratio, Char Soil Index, NDVI, etc.) are most suitable for fire mapping in the Eurasian steppe. I will use selected indices for a Random Forest classification of burned areas and conduct a first accuracy assessment. If the mapping accuracy is insufficient, I will additionally run image segmentation (17, 18).

Once burned area is mapped, I will convert the raster file into vectors to analyze fire patches. To capture temporal changes, I will calculate, for each year: the number of fire patches, their mean areas, and the proportion of burned and unburned areas (19). To estimate differences in fire regime between steppe and abandonment, I will analyze these parameters separately for either land cover classes and for each ecoregion. In addition, I will assess the fire return interval within each class. The I will conduct a regression analysis to identify statically significant relationships between fire regimes and land cover types, ecoregions and year since abandonment. That will allow to specify if there is a lag effect, i.e., if several years of fuel accumulation on abandoned fields is required for fires to emerge.

My fire maps will be essential to assess the current fire regime in the Eurasian steppe, to quantify its changes, and to identify the role of abandonment in these changes. In addition, my analyses of the fire regime will be valuable for a wide range of scientific and management tasks, including specifying fire effects on vegetation (my 2nd objective), wildlife and overall biodiversity; assessing carbon emission; improving the effectiveness of prescribed fires for biodiversity management, and to protect human property.

Objective 2: Estimating vegetation succession due to fires in unplowed steppe and on abandoned fields

Fires have strong effects on vegetation structure, successions and biodiversity (20, 21). Prescribed fires are often used to support grassland biodiversity, at least in North America (22). However, uncontrolled fires can also destroy natural plant communities (7, 23), and Eurasian steppes are not as fire-dependent as North American prairies. Furthermore, even in fire-dependent ecosystems, environmental effects vary a lot with fire frequency and extent, ranging from quite positive to highly negative (24).

In my second objective, I will study the effects of the current fire regime in the Eurasian steppe on vegetation structure, plant biodiversity, and succession patterns in both unplowed steppe and abandoned croplands. I hypothesize that at their current level fires are causing losses of both biodiversity and habitat heterogeneity, and decrease the structural complexity of grasslands, which may curtail the recovery of steppe communities after abandonment. I will focus for this objective on two regions in Kazakhstan: 1) Pavlodar and East Kazakhstan Provinces; 2) West Kazakhstan Province. Both areas encompass more than one ecoregion and contain widespread abandonment of different age, as well as unplowed grasslands. I will conduct fieldwork in both areas and collect information on vegetation structure and plant biodiversity. In addition, I will collect drone-made aerial photos to assess the quality of fire map produced in the first part of my research.

I will define two pairs of new land cover classes, i.e. burned/unburned steppe and burned/unburned abandonment. Based on my already-developed maps, I will select 4-5 test sites where all four classes are present, with burned and unburned classes having similar relief, climate conditions, grazing pressure, and age of abandoned; so differing only in their fire regime. The 'burned' classes will be defined as areas with the mean fire frequency where the time passed after the last fire is close to the mean fireless period

Within each test site I will collect two types of data. For vegetation structure, I will randomly select 15 large plots (0.25-0.5 km^2) for each land cover class and collect drone imagery. Drones are a powerful tool for the detailed mapping of different vegetation types (such as grasses, shrubs, mixed vegetation), shapes of shrubs, and even grass height and biomass (25, 26). For plant biodiversity, I will randomly select 50 plots (10*10 m) within each of the four land cover classes and make a list of vascular plant species for each plot. To analyze vegetation structure, I will make ortophotomosaics from the drone photos using Agisoft software and delineate groups of dominant species (such as *Stipa*, *Festuca*, *Artemisia*, *Caligonum*, large shrubs, rootstock grasses), mixed vegetation (where no single species dominates), and bare ground. Then I will calculate (in percent) the coverage of each group, their total area, the number of patches of each group, and the mean size and shape of patches in order to evaluate patch size distributions. Then I will estimate the variability of these parameters within the four land cover classes and compare the parameters between the pairs of burned/unburned steppe and burned/unburned abandonment. To assess plant biodiversity, I will analyze the total number of species, as well as their ecological groups and life forms, the presence and amount of rare and protected species within each plot, and then test for statistically significant differences between burned and unburned steppe and abandonment. Because all environmental conditions for burned and unburned classes will be controlled for, the resulting differences can be attributed as fire effect.

My results from objective 2 will quantify the effects of fires on vegetation and biodiversity, thereby allow to predict future changes in vegetation, distribution of various plant communities, rare or invasive species, for which certain biotopes provide the best habitats. In practical terms, the results will be important for fire management optimization in protected areas and for steppe restoration on abandoned lands.

Objective 3: Habitat use by rare waterfowl species, spatial-temporal variability of rare waterfowl's stopover sites, and species distributions during migrations in the Eurasian steppe

The Eurasian Steppe is an important staging area for Arctic swans, ducks and geese (9). Numerous lakes surrounded by extensive cereal fields or natural steppes make Northern Kazakhstan among Central Asia's most important stopover site for many migration waterfowl species. GPS-trackers provide detailed information about bird migration, including exact location of preferred habitats at migration stopover sites (27) while land cover maps derived from remote sensing data allow to evaluate factors affecting birds habitat selection. My goals for objective 3 are to identify the most important factors determining habitat selection by waterfowl, evaluating a role of land abandonment (including abandonment of artificial ponds) in habitat selection, and modeling bird distribution during their migrations.

I chose three species: Taiga been goose (*Anser fabalis fabalis*); Red-breasted goose (*Branta ruficollis*); and Bewick's Swan (*Cygnus columbianus bewickii*). All three are nesting endemics of Russia and species of conservation concern (28, 29). I have already compiled data from 46 GPS trackers of Bewick's Swan from 2015 to 2020, 27 GPS trackers of Red-breasted goose obtained in 2013-2015 and in 2019-2020, and 6 GPS trackers of Taiga bean goose from 2017 to 2020 (Fig. 4).

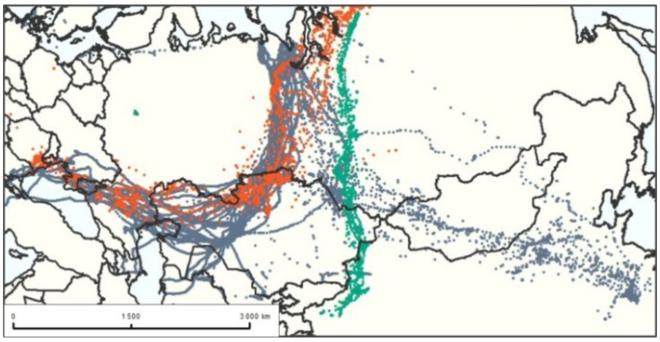

Fig 4. GPS trackers: grey dots-Bewick's Swan , green dots-Taiga been goose, orange dots-Red-breasted goose

I will initially analyze waterfowl movements by applying Dynamic Brownian Bridge Movement Model (30) to extract individual stopover locations from all the GPS data and create annual maps of all stopovers for each species. Then I will calculate (using my land cover maps) a set of metrics: distances between roosts and feeding places (as a daily activity measure); area of lakes, the distances to field boundaries, settlements and roads (as proxies for disturbance intensity); amount and proportion of land cover classes including abandoned fields (as a proxy for landscape heterogeneity); NDVI during growing season (as a proxy for food availability), Landsat land surface temperature data (as a proxy for local weather conditions) (31). I will use time spent by birds in each location as a measure of habitat suitability (dependent variable) and parametrize regression models to evaluate which of the metrics have the highest explanatory power. In addition, I will compare the annual stopover maps for each species to identify spatiotemporal changes of stopover sites and assess whether there is a spatial correlations with land abandonment.

Ultimately, I will predict bird distributions based on the metrics identified in my regression model. For this I will use maximum entropy (MaxEnt) modeling because of its high predictive power (32). The result from these analyses will be maps of probability that conditions are suitable for each bird species. To evaluate the accuracy of the maps I will compare them with the already available ground data reported in annual surveys from 2000-2016 (these data are also in hands).

The results from objective 3 will be two set of maps: a) existing waterfowl stopover sites identified by GPS data, and b) maps of potential distribution of rare waterfowl species during their migrations. Other results will include new data about rare waterfowl ecology, their habitat preferences, stopover changes and environmental drivers of these changes. All of these results will advance understanding of the species' biology, fill blind spots in waterfowl ecology, and be useful for population management, hunting regulations, and the protection of rare species. The maps of potential distribution are expected to have a broad application for ground monitoring of rare waterfowl and the establishment of new protected areas.

Overall significance

Assessment of human-triggered land cover changes, and their effects on biodiversity, is an important part of modern ecology. However, experimental studies of large-scale impact are hardly possible, and local studies may not reveal general trends sufficiently to allow large scale modeling. The Eurasian steppe has undergone a 'semi-natural' experiment allowing to study land cover change processes, and their effects on biodiversity, on a really broad scale. My research of fire dynamics and fire-driven successions will provide new insights into grassland ecology, improve understanding of abandonment-fires relationships, test for positive-feedback loop of repeated fires creating more flammable landscapes with still stronger fire dynamics, and predict vegetation response to fires increase due to climate change, abandonment or other human activities. The fire maps will also be useful for assessing carbon emission and the role of steppe fires in climate change. For zoology, my research will provide new knowledge on rare geese ecology, their migration routes and habitat usage. It will show the level of human-made habitats usage by these species and identify the most important factors affecting their habitat preferences. Because my target species migrate together with other waterfowl, the result will be also useful for scientists studying other Arctic waterfowl. Overall, my interdisciplinary research will pertain to NASA's Earth Science Research Program focus area "Carbon Cycle and Ecosystems" and address NASA science questions "How are global ecosystems changing? What changes are occurring in global land cover and land use, and what are their causes? How do ecosystems, land cover and biogeochemical cycles respond to and affect global environmental change?" On local scale, my research will be useful to improve fire management to protect human property, sensitive landscapes, and rare species, to create new protected areas, and to amend hunting regulations.

Timeline

The research is proposed to start on 09/01/2021 and to finish in the summer of 2024.

Year	2021		2022				2023				2024	
Quarter	3	4	1	2	3	4	1	2	3	4	1	2
Objective 1	D	A	A	MP	MS							
Objective 2				F	D	A	A/F	MP	MS			
Objective 3								A	A	A	MP	MS

D- Data calculation, F-fieldwork, A- Analysis, MP – Manuscript preparation, MS-Manuscript submitting.

References

1. Dubinin, M., Potapov, P., Lushchekina, A., Radeloff, V. (2010). Reconstructing long time series of burned areas in arid grasslands of southern Russia by satellite remote sensing. *Remote Sensing of Environment, 114(8), 1638-1648.* https://doi.org/10.1016/j.rse.2010.02.010
2. Dara, A., Baumann, M., Hölzel, N., Hostert, P., Kamp, J., Müller, D., Ullrich, B., Kuemmerle, T. (2019). Post-Soviet Land-Use Change Affected Fire Regimes on the Eurasian Steppes. Ecosystems, 23, 943–956. https://doi.org/10.1007/s10021-019-00447-w
3. Baumann, M., Kamp, J., Pötzschner, F., Bleyhl, B., Dara, A., Hankerson, B., Prishchepov, A. V., Schierhorn. F., Müller, D., Hölzel, N., Krämer. R., Urazaliyev, R., Kuemmerle, T. (2020). Declining human pressure and opportunities for rewilding in the steppes of Eurasia. *Diversity and Distributions, 26, 1058–1070.* https://doi.org/10.1111/ddi.13110
4. Pazur, R., Prishchepov, A.V., Myachina, K., Verburg, P.H., Levykin, S., Ponkina, E. V., Kazachkov, G., Yakovlev, I., Akhmetov, R., Rogova, N., Bürgi, B. (2021). Restoring steppe landscapes: patterns, drivers and implications in Russia's steppes. *Landscape Ecology, 36, 407–425.* https://doi.org/10.1007/s10980-020-01174-7
5. Grishchenko, M. (2018). Land use changes in Russia and their impact on migrating geese. Wageningen University
6. Freitag, M., Kamp, J., Dara, A., Kuemmerle, T., Sidorova, T.V., Stirnemann, I.A., Velbert, F., Hölzel. N. (2021). Post-Soviet shifts in grazing and fire regimes changed the functional plant community composition on the Eurasian steppe. *Global Change Biology, 27, 388–401*. https://doi. org/10.1111/gcb.15411
7. Dzhapova, R. R. (2008) Dynamics of pastures and hayfields of Kalmykia. Elista, Kalmyk University, Russia. [Dinamika pastbishch i senokosov Kalmykii]. 176 p. (in Russian)
8. Newton, I. (2006). Can conditions experienced during migration limit the population levels of birds? *Journal of Ornithology*, *147, 146–166*. https://doi.org/10.1007/s10336-006-0058-4
9. Cuthbert, R. J., Aarvak, T., Boros, E., Eskelin, T., Fedorenko, V., Karvonen, R., Kovalenko, A., Lehikoinen, S., Petkov, N., Szilágyi, A., Tar, J., Timonen, S., Timoshenko, A., Zhadan, K., Zuban, I. (2018). Estimating the autumn staging abundance of migratory goose species in northern Kazakhstan. *Wildfowl*, *68, 44-69.* https://wildfowl.wwt.org.uk/index.php/wildfowl/article/view/2676
10. Vangeluwe, D., Rozenfeld, S. B., Volkov, S. V., Kazantzidis, S., Morosov, V. V., Zamyatin, D. O., Kirtaev, G. V. (2018). Migrations of Bewick's Swan (Cygnus bewickii): New Data on Tagging the Migration Routes, Stopovers, and Wintering Sites. *Biology Bulletin, 45, 706–717*. https://doi.org/10.1134/S1062359018070178
11. Beck, H. E., Zimmermann, N. E., Mcvicar, T. R., Vergopolan, N., Berg, A., Wood, E. F. (2018). Data Descriptor : Present and future Köppen-Geiger climate classification maps at 1-km resolution. *Nature Publishing Group, 5, 180214.* https://doi.org/10.1038/sdata.2018.214
12. National atlas of Russia, on-line version, https://xn--80aaaa1bhnclcci1cl5c4ep.xn--p1ai/cd2/english.html
13. National atlas of the Republic of Kazakhstan. (2010). Almaty, Institute of Geography of Republic Kazakhstan.
14. Pavlejchik, V. M. (2016). An activation of steppe fires in Voga - Ural region [K voprosu ob aktivizacii stepnyh pozharov (na primere zavolzhsko-ural'skogo regiona)].

Proceedings of Voronezh State University. Series: Geography. Geoecology [Vestnik VGU, Geografiya, Geoekologiya], *3*, *15–25*. (in Russian)
15. Long, T., Zhang, Z., He, G., Jiao, W., Tang, C., Wu, B., Zhang, X., Wang, G., Yin, R.(2019). 30 m Resolution Global Annual Burned Area Mapping Based on Landsat Images and Google Earth Engine. *Remote Sensing, 11(5), 489.* https://doi.org/10.3390/rs11050489
16. Dubinin, M. Y. (2010). Effects of land use change on fire, vegetation and wildlife dynamics in arid grasslands of Southern Russia. University of Wisconsin-Madison.
17. Stroppiana, D., Bordogna, G., Carrara, P., Boschetti, M., Boschetti, L., Brivio, P. A. (2012). A method for extracting burned areas from Landsat TM/ETM+ images by soft aggregation of multiple Spectral Indices and a region growing algorithm. *ISPRS Journal of Photogrammetry and Remote Sensing, 69, 88-102.* https://doi.org/10.1016/j.isprsjprs.2012.03.001.
18. Goodwin, N. R., Collett, L. J. (2014). Development of an automated method for mapping fire history captured in Landsat TM and ETM+ time series across Queensland, Australia. *Remote Sensing of Environment, 148, 206-221.* https://doi.org/10.1016/j.rse.2014.03.021.
19. Archibald, S., Lehmann, C.E., Go´mez-Dans, J.L., Bradstock, R.A. (2013). Defining pyromes and global syndromes of fire regimes. *Proceedings of the National Academy of Sciences 110 (16) 6442-6447*. https://doi.org/10.1073/pnas.1211466110
20. Bond, W. J., Keeley, J. E. (2005). Fire as a global "herbivore": The ecology and evolution of flammable ecosystems. *Trends in Ecology and Evolution*, *20(7), 387-394*. https://doi.org/10.1016/j.tree.2005.04.025
21. D'Odorico, P., Okin, G. S., Bestelmeyer, B. T. (2012). A synthetic review of feedbacks and drivers of shrub encroachment in arid grasslands. *Ecohydrology, 5(5), 520-530.* https://doi.org/10.1002/eco.259
22. Block, W. M., Conner, L. M., Brewer, P. A., Ford, P., Haufler, J., Litt, A., Masters, R. E., Mitchell, L. R., Park, J. (2016). Effects of Prescribed Fire on Wildlife and Wildlife Habitat in Selected Ecosystems of North America. *The Wildlife Society Technical Review 16-01*. The Wildlife Society, Bethesda, Maryland, USA
23. Nemkov, V. A., Sapiga, E. V. (2002). Conservation of steppe in protected areas [Sohranenie stepnyh ekosistem v uslovijah zapovednogo rezhima]. *Vestnik of OSU*, 76–83. (in Russian)
24. Collins S. L, Calabrese L. B. (2012). Effects of fire, grazing and topographic variation on vegetation structure in tallgrass prairie. *Journal of Vegetation Science*, *23*(3), https://doi.org/10.1111/j.1654-1103.2011.01369.x
25. Cunliffe, A.M., Brazier, R. E., Anderson, K. (2016). Ultra-fine grain landscape-scale quantification of dryland vegetation structure with drone-acquired structure-from-motion photogrammetry.*Remote Sensing of Environment,183, 129-143.* https://doi.org/10.1016/j.rse.2016.05.019.
26. Forsmoo, J., Anderson, K., Macleod, C.J.A.,, Wilkinson M.E., Brazier, R.(2018). Drone-based structure-from-motion photogrammetry captures grassland sward height variability. *Journal of Applied Ecology, 55, 2587–2599.* https://doi.org/10.1111/1365-2664.13148
27. Lei, J., Jia, Y., Zuo, A., Zeng, Q., Shi, L., Zhou, Y., Zhang, H., Lu, C., Lei, G., Wen, L. (2019). Bird satellite tracking revealed critical protection gaps in East Asian–Australasian flyway. *International Journal of Environmental Research and Public Health, 16(7), 1147.* https://doi.org/10.3390/ijerph16071147
28. IUCN (2017) The IUCN Red List of Threatened Species. https://dx.doi.org/10.2305/IUCN.UK.2017-3.RLTS.T22679954A118577901.en.