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Combining virtual and in-place field crews to model pollinator species shift in the Greater Yellowstone Ecosystem

S. Whipple [a,b,*], A. Rohlf [b], C. Dominguez Vasquez [c], D. Dominguez [d], G. Bowser [b], P. Halliwell [b,e]

[a] Colorado State University Graduate Degree Program in Ecology (ORCID: 0000-0001-9280-1195), Colorado State University Fort Collins, CO 80523, USA
[b] Colorado State University Department of Ecosystem Science and Sustainability (ORCID: 0000-0001-5548-9876) (ORCID: 0000-0001-7994-2620), Colorado State University Department, 1476 Fort Collins, CO 80523, USA
[c] Colorado State University Department of Fish, Wildlife and Conservation Biology (ORCID: 0000-0001-6449-0924), Colorado State University Fort Collins, CO 80523, USA
[d] Colorado State University Department of Watershed Science, Colorado State University Department, 1476 Fort Collins, CO 80523, USA
[e] Colorado State University Natural Resource Ecology Laboratory (ORCID: 0000-0001-8911-719X), Colorado State University Department, 1499 Fort Collins, CO 80523, USA

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ABSTRACT

Insect pollinators (bees and butterflies) face global challenges as climate change impacts species occurrence (or extinction) within managed and protected areas. While species decline is predicted for invertebrate species, especially in sensitive ecosystems such as high alpine systems, little is known about species responses to climate change. This study seeks to understand the impact of climate change on pollinators in high elevation ecosystems, specifically within Yellowstone and Grand Teton National Parks. These parks are connected protected areas in the United States that act as a large reservoir for conserving species, including pollinators. Students performing research amidst the COVID-19 pandemic were divided into two virtual teams (bug team and climate team) to assess historic climate data, natural history collections and plant/pollinator data from Yellowstone and Grand Teton National Parks. Each team was tasked with addressing the larger question of climate change impacts on pollinators within protected areas while also gaining interpersonal, collaborative learning skills through their experience. This paper highlights two case studies tied to pollinator decline. The first assesses citizen science and natural history collection databases to predict and field test species occurrence within the parks. The second identifies suitable habitats for species occurrence locations. Lastly, this paper emphasizes the learning outcomes students had from virtual and hybrid field settings and offers suggestions for applications towards field-based research efforts.

1. Introduction

Insect pollinators face global challenges as changing climates drive some species towards extinction, while other species thrive (Forister et al., 2021). The environmental drivers of these differing responses among insects include habitat loss and fragmentation, urbanization, and climate change. As climate is becoming more variable on a global scale, shifts in temperature, precipitation, and other natural hazards over time will have large implications in species ranges (Svenning, 2008) even in areas protected from immediate impacts of land use and land cover change (Hill et al., 2002; Shukla et al., 2019).

The cryosphere and high elevation mountain systems face pressures as well with documented glacial retreat driving large scale ecosystem changes (Pörtner et al., 2019). The Intergovernmental Panel on Climate Change (IPCC) projects that these shifts in hydrologic and temperature cycles will impact the persistence and migration of species that are

Acronyms: CO-WY AMP, Colorado-Wyoming Louis Stokes Alliance for Minority Participation in Science; CSU, Colorado State University; DEM, Digital Elevation Model; GBIF, Global Biodiversity Information Facility; GYE, Greater Yellowstone Ecosystem; IPCC, Intergovernmental Panel on Climate Change; IPBES, Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services; NEON, National Ecological Observatory Network; NHC, Natural History Collection; NOAA, National Oceanic and Atmospheric Association; USGS, United States Geological Survey.

* Corresponding author at: Colorado State University Department, 1476 Fort Collins, CO 80523, USA.
E-mail addresses: Sarah.Whipple@rams.colostate.edu (S. Whipple), cristald@rams.colostate.edu (C.D. Vasquez), ddomino@rams.colostate.edu (D. Dominguez), gbowser@colostate.edu (G. Bowser), philip.halliwell@colostate.edu (P. Halliwell).

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dependent on certain elevational gradients (Pörtner et al. 2019). While vertebrate species decline is predicted across alpine systems, the responses to climate change by invertebrate pollinators is less predictable. In high elevation areas that include many national parks and preserves, species shifts are predicted to be more dramatic, yet the species diversity of critical ecosystem services (such as pollination) are largely unknown (IPBES, 2016).

Two protected areas in the Rocky Mountains, Yellowstone, and Grand Teton National Parks, have already documented climate change impacts with early spring emergence of hibernating animals and earlier plant phenology patterns (CaraDonna et al., 2014; Middleton et al., 2013), while also facing major 1000-year fires in the past 30 years (NWCG, 2021; Westerling, 2016; Westerling et al., 2006). These same parks also have projected summer temperatures increasing 8–10 °F by 2100 (Westerling et al., 2011) with concurrently predicted losses of biodiversity as cold adaptive species experience range contractions.

The pollinator diversity of the national parks and protected areas within the Rocky Mountain region has received minimal attention by federal managers. Several small and isolated studies have developed a limited historic dataset across the Greater Yellowstone Ecosystem (GYE), an 890,000-ha area in northern Wyoming, southern Montana, and eastern Idaho that includes Yellowstone, Grand Teton National Parks and seven surrounding National Forests (Bowser, 1988; Lutz, 1989; Bagdonis and Opler, personal communications; Auckland et al., 2004; Dillon, 2011; Gompert et al., 2010; Rykken et al., 2014). While the GYE land management agencies work together on regional issues and have documented shifts in plant, invertebrate, and animal communities in response to climate change (Hansen and Phillips, 2018), the patterns of pollinator decline, as evidenced through few natural history collections and previous research efforts, suggests that species decline is highly inconsistent. More recent introductions of large-scale datasets through citizen science, where the public contributes towards scientific efforts, have great potential to elucidate patterns of species shifts within the GYE. In addition, emerging mobile phone technology has greatly increased the useability of citizen science datasets including better taxonomic and location accuracy and the ability to tie virtual datasets together with existing natural history collections that are now digitally available. This research sought to understand the impact of climate change on pollinators in high elevation ecosystems and how students could utilize online databases (climate and insect-related) to better inform field sampling efforts.

1.1. Virtual databases and field verifications

The Coronavirus (COVID-19) pandemic over the summer of 2020 altered many of the traditional methods to teach and lead a field course in the ecological sciences. Engaging students in field-based research using an online experience led to many innovative approaches (Krause et al., 2021; Pennisi, 2020). With these uncertainties came an opportunity to learn new methods for data collection and to combine virtual datasets with limited field excursions that were permitted under travel restrictions during the pandemic. The Pollinator Hotshots, a field experience for diverse students through a partnership with the Colorado-Wyoming Louis Stokes Alliance for Minority Participation in Science (CO-WY AMP), developed a hybrid framework of virtual and place-based learning on pollinator diversity and climate change shifts in the GYE. As fieldwork took a hiatus due to the pandemic, research teams had to be innovative in flexible in their approaches to scientific discovery. The Pollinator Hotshots' ability to pivot research objectives into a hybrid space while obtaining similar learning and research goals as an in-person field opportunity was successful.

2. Methods and tools

Eleven student researchers from Colorado State University (CSU), CO-WY AMP and one international intern from Dijon, France, participated in a twelve-week research experience focused on the GYE. The student researchers were divided into two virtual teams (bug team and climate team) to assess historic climate data, natural history collections and plant/pollinator data from the GYE with focus on three preexisting research sites (two in Grand Teton and one in Yellowstone) and one new site (Beartooth Plateau). Each team was tasked with addressing the larger question of impacts of climate change on pollinators within protected areas and students self-divided into either the bug or climate teams and chose an organism or system of interest (Fig. 1). Student teams met each day on Zoom to set goals, socialize with their peers, write, analyze data, and hear from guest contributors. Each team recorded progress and created a common dataset using Epicollect5 where data could be entered from the field for field observations and parameters could be matched against field observations. Also, during the virtual team activities, additional online platforms such as Slack were used to share data files, ask questions, and keep in contact during the working day.

2.1. Natural history collections (bug team)

While working virtually, the bug team constructed a historical database of bees, butterflies, and flowering plants from 1850 to 2019 from digitally archived Natural History Collection (NHC) sources. The metadata included: species observed, location, date of record, pictures, and specimen condition. Data was then compared to recent citizen science pollinator collections completed by the Pollinator Hotshots since 2017 housed on iNaturalist. For example, on the bug team, one student (from Dijon, France and was unable to travel to the US due to the COVID pandemic) focused on gathering data on bumble bees for Yellowstone and particularly on species shifts and phenology, while another student on the same team (located in Colorado) focused on fritillary butterflies. The bug team worked on virtual searching of natural history collections to map species within the GYE. Where location data were usable, the students mapped species locations in association with the existing sites and made predictions on species abundance at other sites (e.g., which species of bumble bees would be predicted to be at that site for a given time of year). Only species records with locational accuracy of 100 m were used in this spatial analysis; all other data were recorded for trend occurrence but not used in the final analysis. Natural history datasets used in this study included museum repositories such as the Gillette Museum of Arthropod Diversity at Colorado State University, the Smithsonian Institute, and Global Biodiversity Information Facility (GBIF) database. Additional butterfly species data specific to the parks were compiled by USGS (Opler) and citizen scientists (via iNaturalist). While these datasets are somewhat limited in taxonomic scope, observer bias (such as those seen in NHCS), and locational accuracy, researchers balanced these limitations out by surveying multiple databases.

2.2. Climate modeling (climate team)

The climate team gathered digital information on the historical climate regime of the GYE, including temperature, precipitation, and snowpack, from databases such as United States Geological Survey (USGS), National Ecological Observatory Network (NEON), National Oceanic and Atmospheric Association (NOAA), and Natural Resources Conservation SNOTEL data (Table 1). The Rocky Mountain region of the western United States is characterized by steep mountain interfaces with glaciers and persistent snowfields having documented increasing temperature and rapid glacier retreat. Protected areas within the Rockies have documented dramatic losses in glaciers and earlier spring flooding (Romme, 1982). Much of the high elevation habitat of the Rockies is within protected area management by either the federal government or state entities. Generalized climate trends were compiled in conjunction with pollinator seasonal patterns and compared to recent climate data collected by the Pollinator Hotshots since 2017. The climate team used GIS to map climate patterns for each of the study areas to recreate

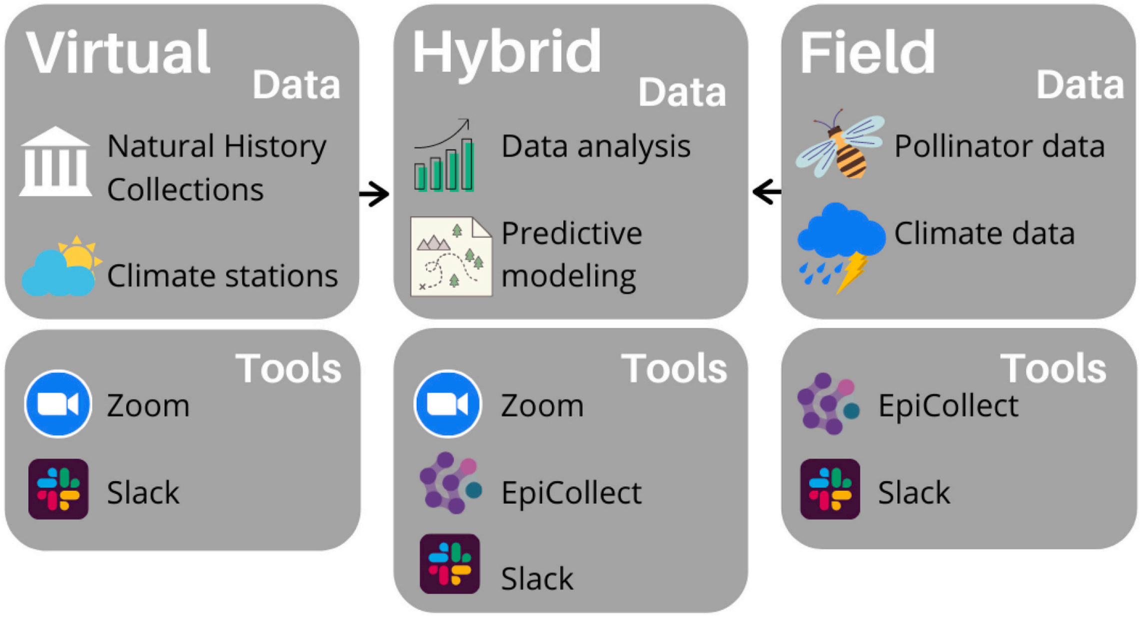

Fig. 1. Schematic outlining the different datasets and tools used by the Pollinator Hotshot team. Virtual and field datasets (pollinator and plant collections and climate databases) were assessed by hybrid working teams and facilitated in predictive modeling. Overlaps in virtual tools ensured that communication and data collection/file sharing was consistent across working teams.

climate variables that could document species shifts. For example, snow free days from SNOTEL or other sites were indicative of when different areas of the park would be snow free. Other data sets, such as NEON or localized weather stations, provided dynamic maps of climate variables and trends seen across the GYE. These data were all compiled and mapped. Lastly, the climate team worked on creating prediction maps using topography and habitat variables available from online databases to predict on the ground species presence by searching for known habitat parameters such as wet meadows and forest openings. The climate team dealt with limitations in locational accuracy across databases, varying time scales, and differing satellite resolutions, but the researchers balanced these limitations out by standardization climate variables in their suitability analysis.

2.3. Data analysis: mapping fritillaries and violets

Using all the data collected from the field and historical data, both the Bug and Climate team collaborated to create an online map through ArcGIS Online of the violets (plants) and fritillaries (butterflies) as a species interaction example. This project used violet and fritillary coordinates gathered from NHCs and iNaturalist to compare whether fritillaries would be found in areas with host plants, as well as to predict additional areas for fritillary observations. Once the GPS coordinates were uploaded to iNaturalist, data of any fritillaries and violets recorded in the GYE were extracted from the online platform.

Fritillary and violet coordinates gathered from NHC and iNaturalist were used to 1) predict whether fritillaries would be found in areas with host plants 2) anticipate other areas where fritillaries could be observed and 3) predict whether fritillary abundance appeared to be affected by fluctuating temperatures. Online coordinates of the fritillaries and violets based on habitat maps were combined in ArcGIS for spatial analysis. First, on iNaturalist, fritillaries and violets were searched. Only species records with locational accuracy of 100 m were used in this spatial analysis; all other data were recorded for trend occurrence but not used in this analysis. The extraction of the data set of both species was done separately to show a map of observations uploaded by citizen scientists. The search was narrowed down to only view Teton County by selecting the general area of GYE, so only observations in this area were highlighted. Spatial information, longitude, and latitude were downloaded and extracted as an excel file then combined into one map through ArcGIS Online (Fig. 2).

2.4. ArcGIS suitability predictive modeling

This suitability analysis model was created to identify locations where pollinators were likely to be present and could be easily accessed by the field crew (Fig. 3). The habitat suitability analysis identifies attributes and criteria indicative of pollinator collection sites from previous experience and observations. The layers were reclassified by areas that do or do not meet the criteria for species of interest (based on natural history data above). Compiled maps included a weighted overlay of each reclassified layer that generated sites which were then prioritized based on accessibility via road or trail. Sites were then verified by field crews during different field expeditions. While this predictive model may have excluded some field locations, the reclassification of layers in multiple stages reduced any discrepancies in site suitability.

2.5. GIS analysis steps

The attributes and criteria were gathered from historic natural history collection sites and previous field experience of pollinator collections in the GYE. The pollinator habitat attributes included aspect ratio, water sources and elevation. Of these attributes the criteria identified were areas in which slopes were not north facing (i.e., an aspect angle greater than 30° and less than 330°), within 1000 m of a water source and higher than 1524 m in elevation. Of these attributes the criteria identified were areas which were less than 1000 m away from trails or roads, a slope angle of less than 11°, and no larger than 80,000 m^2. Data layers were gathered from publicly accessible databases by multiple members of the climate team to be used in the GIS model. These databases included NRCS data gateway, NWIS hydrology, NPS databases and other similar sources. These data layers included National Park boundaries, US Forest Service trails, streams, rivers, and Digital Elevation Models (DEM) covering the entire GYE. All but the DEM layer began as vector layers which made downloading easier. Layers were also clipped to cover the GYE to make processing faster while still maintaining the ability to complete an analysis in any smaller more specific area in the

Table 1
Climate databases and variables pulled for modeling purposes.

Online database name	Data available	Link to database:
IPCC SROCC	Synthesis international climate report (with regional findings)	https://www.ipcc.ch/srocc/chapter/chapter-2/
National Climate Assessment (NCA)	Synthesis national climate report (with regional findings)	https://nca2014.globalchange.gov/
Montana Climate Assessment Report	Synthesis state-level climate report	https://montanaclimate.org/
Idaho Climate Assessment Report	Synthesis state-level climate report	https://nca2018.globalchange.gov/
Wyoming Climate Assessment Report	Synthesis state-level climate report	https://nca2018.globalchange.gov/
Western Regional Climate Center (WRCC)	Partnerships with other agencies (NOAA, National Climate Data Center); climate data writ-large (weather, wind speed, precipitation, and more)	https://wrcc.dri.edu/
Natural Resources Conservation Service (NRCS)	Climate data writ-large (weather, wind speed, precipitation, and more)	https://www.nrcs.usda.gov/wps/portal/nrcs/site/national/home/
National Water Information System (NWIS)	Water-specific data (surface water, groundwater, water quality, use)	https://waterdata.usgs.gov/nwis
National Ecological Observatory Network (NEON)	Climate data (temperature, precipitation, and more) but also phenology data (green-up)	https://data.neonscience.org/data-products/explore
PRISM	Climate projections (temperature, precipitation, etc.) on a 30-year normal time scale	http://www.prism.oregonstate.edu/
National Phenology Network (NPN)	Phenology data (green-up, first bloom, peak bloom, anomalies)	https://www.usanpn.org/data
USGS Satellite Data	Includes satellite information such as land cover, radar, digital elevation, and Landsat	https://earthexplorer.usgs.gov/
National Park Service	NPS-specific data (park boundaries, elevation, vegetation, and more)	https://public-nps.opendata.arcgis.com
NOAA NCDC	NOAA Weather station data (temperature, precipitation, weather radars, and more)	https://www.ncdc.noaa.gov/cdo-web/datatools/findstation
ForWarn Assessment Viewer	Predictions based on Forest Change due to wildland fire, insect and disease surveys, and early detection of phenological shifts	https://forwarn.forestthreats.org/fcav2/

region such as Yellowstone and Grand Teton National Parks.

To complete a weighted overlay, each layer was reclassified into raster layers of values buffering (1000 m) from water sources, roads, and trails. For slope and aspect, the DEM layer was reclassified into non-north facing areas. Cells that met criteria were given a value of 1 (suitable), while all other cells were given a value of 0 (not suitable). Suitability habitat models were built based on the final weighted overlay of each of the reclassified layers. After three iterations using the suitability criteria and buffers, 75 sites were identified in Yellowstone, Teton, and the GYE areas.

2.6. Field work

Field expeditions during the summer of 2020 were defined by health and travel restrictions. Small crews were allowed to travel for up to ten days with equivalent quarantine days scheduled in between each field expedition. During the summer of 2020, five field expeditions were approved between mid-June and late August. Students self-selected for the field expeditions with approximately half of the total team remaining virtual for each expedition. Given a wide variety of personal travel restrictions or health issues, the composition of the field crews shifted over the summer with some students remaining virtual the entire summer while others rotated in and out of field crews.

2.7. Student learning surveys

All students were surveyed using qualitative methods with semi-structured surveys conducted at the beginning and end of the field season along with weekly reflection survey writing sessions (Table 2). All data were compiled and coded for analysis after the completion of the field season. A smaller team also completed professional development presentations that were completed in late fall of 2020 with final survey and project close out in winter of 2021. Because of the crew dynamics throughout the field season, nearly all student learning surveys were complete, but a few students opted out of their weekly reflections given personal commitments.

3. Results

3.1. Field datasets: pollinator and climate data

Within the GYE, eight sites were sampled in Yellowstone for the past three field seasons starting in 2017, four sites were sampled in Grand Teton starting in 2017, and four additional sites were sampled in the Gallatin and Shoshone National Forests surrounding the parks in 2020. At each site, student researchers split up into three teams: plant surveyors, pollinator surveyors, and photographers. Student researchers collected climate variables including temperature, wind speed, relative humidity, and percent cloud cover at the beginning and end of each field sampling period using a Kestrel 3500 (Kestrel Instruments, 2021) and/or a HOBO USB micro station data logger (Onset Computer Corporation, 2021). Surveys were only conducted during optimal pollinator flight conditions: between 9:00–17:00, with temperatures between 24 and 38 °C, with less than seven meters per second wind speed, and with less than 30% cloud cover (Robinson et al., 2012). Plant surveyors recorded the phenological stage (budding, 50% bloomed, full bloom, 50% senesced, and senesced) of the 15 most dominant plants present within the site. Flower color, shape, and location were also recorded. All photographed observations were uploaded and confirmed by other citizen scientists within the iNaturalist database. Two pollinator surveyors walked the transect area for the entire sampling time using traditional Pollard walks to track species abundance (Pollard, 1977), netted any specimens they could successfully collect, and placed specimens in test tubes or petri dishes. Once collected, specimens were placed in a cooler with ice packs then photographed on their dorsal, ventral, and face sides. Surveyors took note of the time, sex of specimen (if this could be identified), amount of “wing” or body wear, and behavior.

3.2. Field verification of habitat models with citizen science data

For the existing database verification, we drew upon the citizen science and NHC resources we had already gathered (Fig. 4). Blue butterflies represent citizen science observations taken from iNaturalist overlaid on the suitability map to give a graphical representation of the accuracy of the model. In general, the iNaturalist observations fell near or within the green areas, which represent where the most suitability criteria are met. Manual field validation at Phelps Lake/ Death Canyon, Two Oceans and Emma Matilda Lake were completed over the 2020 field season with positive collection results at each (Fig. 4). High resolution spatial layers of topo climatic parameters are being used in similar site suitability analysis to great effect (Tomlinson et al., 2018).

3.3. Student learning survey outcomes

Students each completed 13 surveys across the duration of the internship for a total of 130 reflective surveys. Because of the differences

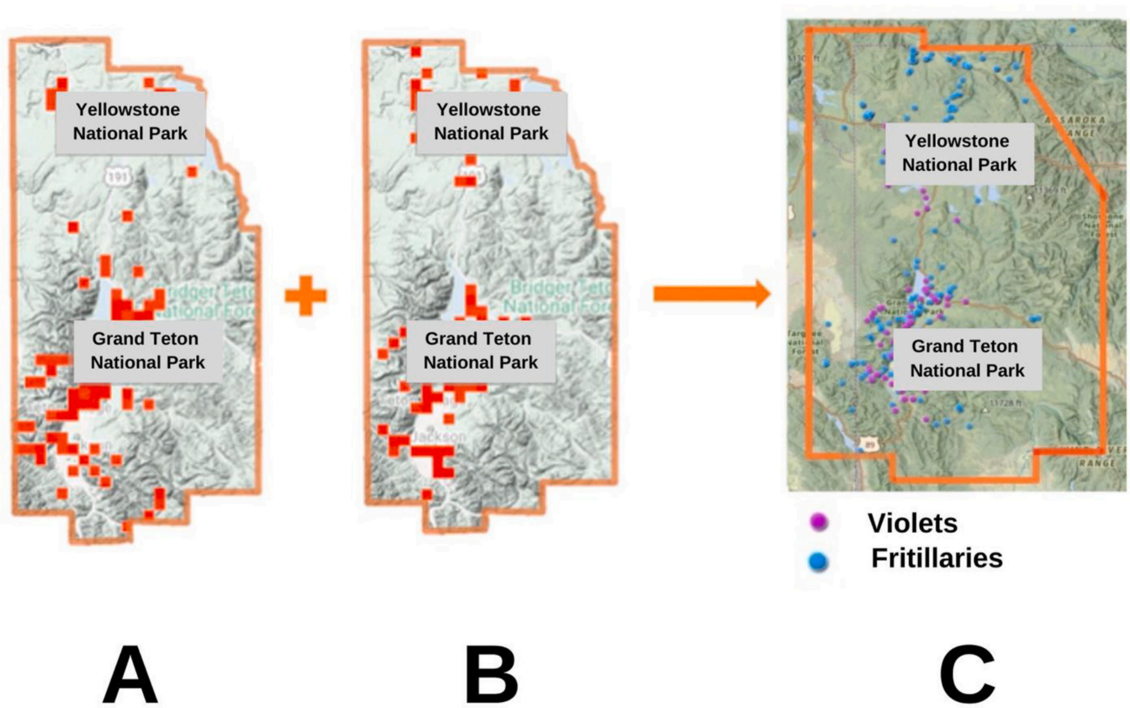

Fig. 2. Both fig. A and B contain all the observations of fritillaries (A) and violets (B) in the GYE made by Hotshots and other citizen scientists and uploaded to iNaturalist. The coordinates were combined to create a map on ArcGIS Online of both species to be used for further evaluation.

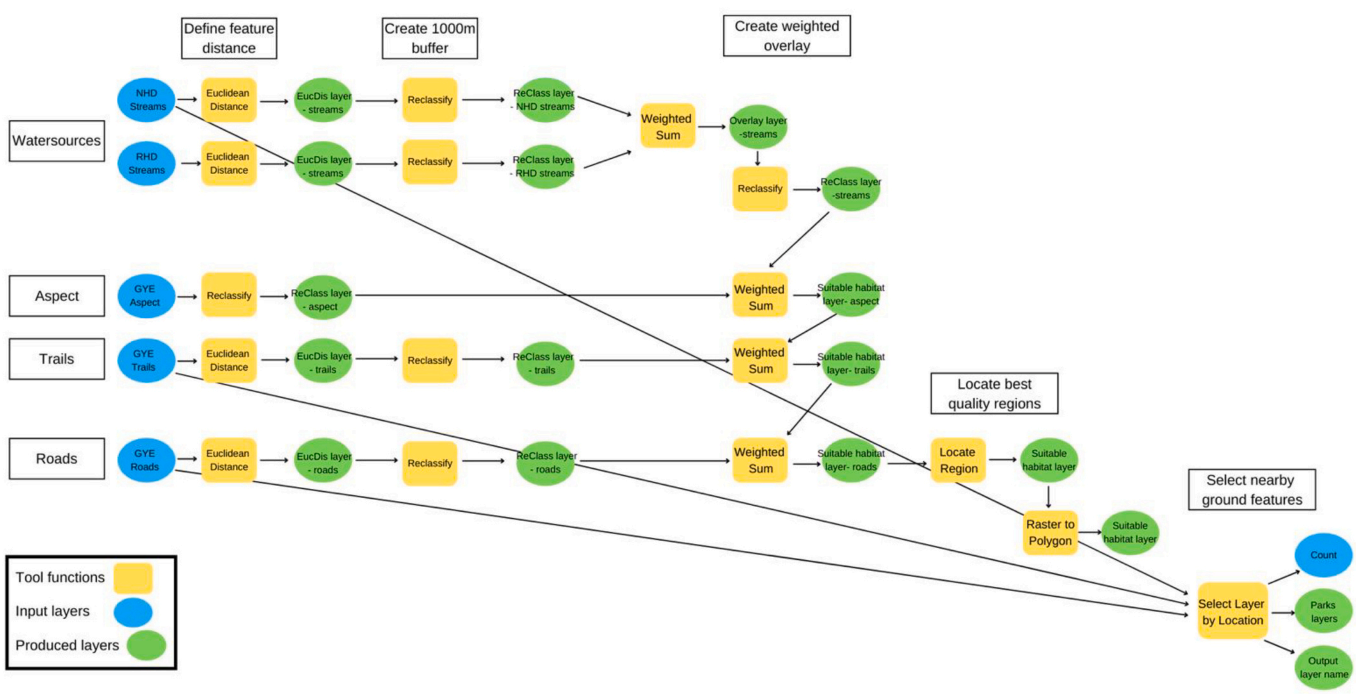

Fig. 3. ArcGIS Model builder flow diagram showing the suitability analysis workflow. Starting with input layers (blue) on the left and analysis functions (yellow) proceeding from left to right. Produced layers (green) are raster layers and are combined at the end to create a point layer of suitable sites. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

in student time commitments, scientific interests, and working location, students' responses to questions on goals (individual and team) varied. Themes found within surveys included: difficulties transitioning to remote working, benefits of collaborative working and team communication platforms, enjoyment of team bonding and professional development activities such as group bug catching, guest lecturers, and scavenger hunt work, leadership and sense of confidence, and overall scientific exploration (Table 3).

4. Discussion

Some records indicate that butterfly and bee populations within

Table 2
Reflective writing questions students completed during the summer internship. * Indicates questions only asked to start and finish the internship.

Reflective writing questions
What have you learned thus far when it comes to the internship/virtual learning?
What has been challenging when it comes to the internship/virtual learning?
What have you most enjoyed during the first few weeks of your internship?
What are your PERSONAL goals for the upcoming week prior to heading into the field?
What are your TEAM goals for the upcoming week prior to heading into the field?
What are your PERSONAL goals for when we are in the field?
What are your TEAM goals for when we are in the field?
How is your energy level on a scale of −2 to +2 (−2 is very low, 0 is neutral, and + 2 is very high)
What motivates you to live a sustainable lifestyle? *
What motivates you to major in your discipline? *
Share your thoughts about the Hotshot experience, what you learned, and the leadership experiences. *

European national parks have declined by 50% over the past 20 years (Hallmann et al., 2017). United States National Parks lack comprehensive, long-term biodiversity monitoring programs, especially regarding invertebrate specimens including insect pollinators (Sánchez-Bayo and Wyckhuys, 2019; Shafer, 1999), so tracking the rates of insect pollinator species occurrence and decline within these areas is hard to accomplish. Through this project, students assessed pollinator and climate trends within Grand Teton and Yellowstone National Parks, two of the largest intact protected areas in the United States, using citizen science, natural history collections, and climate datasets. Nevertheless, students were able to understand these trends while working remotely amidst the COVID-19 pandemic. Through this, learning outcomes such as project co-creation and data ownership emerged.

4.1. Student learning outcomes (co-creation, data ownership)

Science tools that are accessible to all have the potential to include diverse perspectives into the scientific decision-making process. Participating in a citizen science project using such tools can serve as a brief educational intervention during a student's academic journey in the environmental sciences by changing the connection between data collection (Halliwell and Bowser, 2019; Leong and Kyle, 2014). Despite never meeting some of their peers due to the online setting, students left the 2020 Hotshots with new colleagues, tools, and scientific exploration: “*Being on the field team, my accomplishments came as a team, we were able to get more information on the species that exist on our ways up to the trail. At first, I didn't understand how this fit with the data that we were collecting*

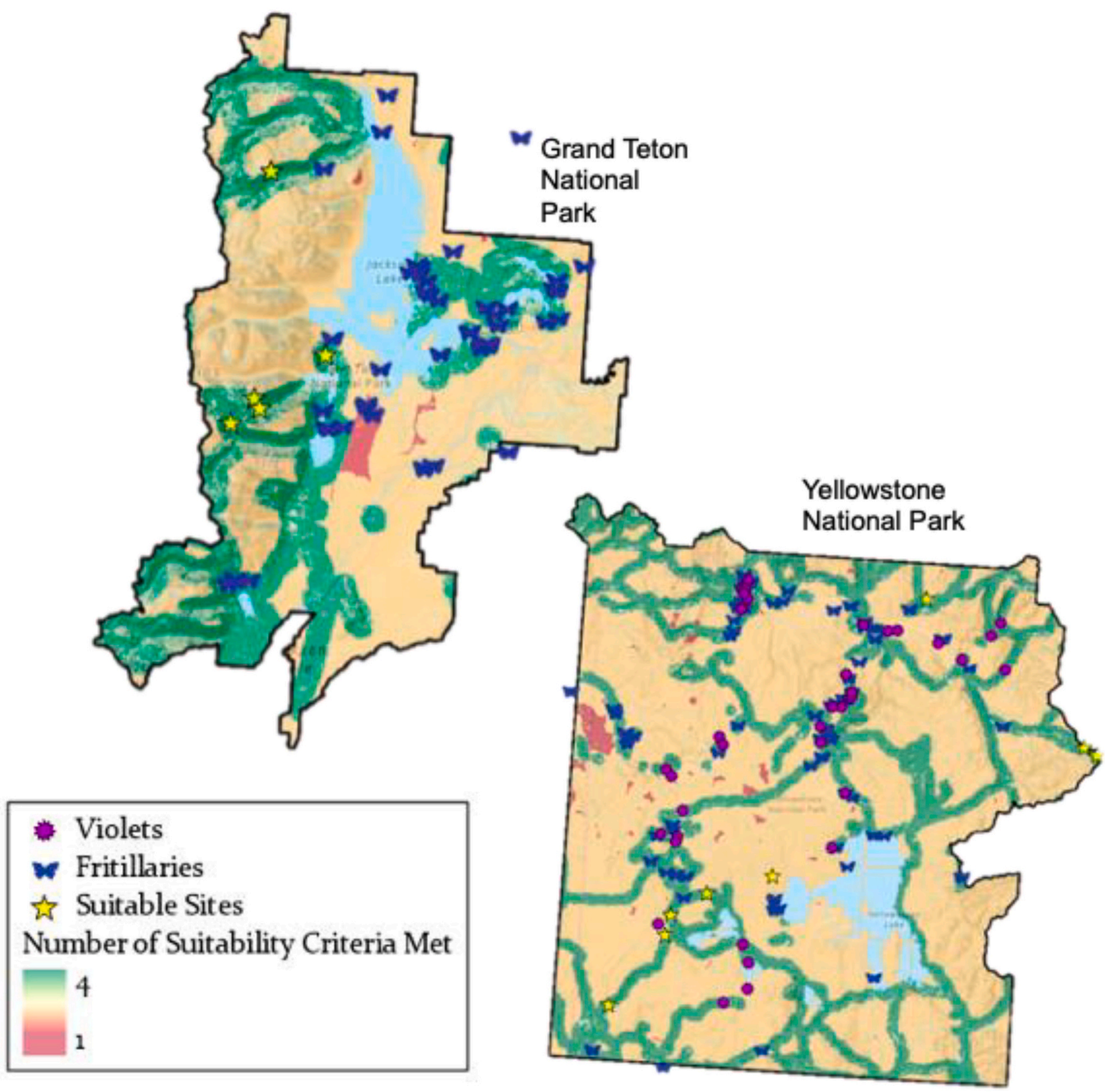

Fig. 4. Overlaid are suitable sites identified by analysis and field observations of fritillaries and violets from iNaturalist databases. Suitability criteria were met based on access to roads, water sources, trails, and habitat variables (slope, aspect, etc.).

Table 3
Examples of student reflective responses based on overarching themes.

Theme	Examples
Remote Working	"Virtually learning has been a new experience when it started a couple months ago with my classes and this internship. Throughout those couple months I've learned that learning virtually takes real dedication to be focused on the topics and what tasks need to be done for the day. I've also learned how connected a group of people can actually be considering that some of us live hundreds of miles away." (Undergraduate Student, Female, Colorado) "I still find the virtual learning experience challenging because of the amount of time that I have spent behind a screen but I am trying to be a lot better about going outside and taking photographs of plants and insects." (Undergraduate Student, Male, Colorado)
Collaborative Teams	"...To connect every day with people and don't feel alone in my work." (Graduate Student, Female, France) "I have learned that it can be useful to have a field team and continue to have an online team. This allows for in person collection but with a greater ability to continue processing previous and new data. The internet connection in the field does make things a bit harder to accomplish but it is getting better all the time and may prove even more useful in the future." (Undergraduate Student, Male, Colorado)
Professional Development and Team Bonding	"This week I really enjoyed the guest speaker, I liked how it connected with everything and made me think about how literally everything is connected." (Undergraduate Student, Female, Colorado) "I have really enjoyed the opportunity to work with professionals in the field of natural resources and be able to learn from their experience." (Undergraduate Student, Female, Colorado) "This week I have enjoyed talking through the abstract for the AGU poster, because that is a cool upcoming event that will be a new experience and hopefully a fun time. I have never had the opportunity to participate in a professional conference and it will be interesting to see our work in that setting." (Undergraduate Student, Female, Colorado)
Leadership	"I also was able to lead during this internship which I had not had recent experience; being put in a leadership position helped me regain my confidence in my leadership abilities. The experience also reminded me that taking my own initiative to start projects can lead to a better experience and can help others by drawing them into what my project contains." (Undergraduate Student, Male, Colorado)
Scientific Exploration	"I have learned a lot about pollination and pollinators through this internship and am very excited that I can see it first hand in my backyard and in open spaces around me" (Undergraduate Student, Male, Colorado) "I've learned the very basics of GIS, which is very helpful for the climate team, and I've also learned about converting data into different forms like CSV into an excel sheet." (Undergraduate Student, Female, Colorado)

based on last year, but the more I think of it, I figured out it's another component to track species in National Parks. Learning what species are common surrounding trails can help us understand how a human presence changes the ecosystem and what species are hardy enough to adapt to changing conditions" (Undergraduate student, Male, Colorado).

The ability to create and "own" data gathered on smartphones using scientific databases and apps democratizes science where technology allows co-creation of research questions, datasets, and discoveries by anyone. The discovery of something new, such as a species record, can significantly increase attachment in both identity (connections resulting from social and emotional elements) and dependence (connections resulting from doing what one enjoys) (Haywood, 2016). For example, as underrepresented student researchers participate in science discovery using citizen science, how they perceive their own potential to be a scientist can change (Davis et al., 2012; Halliwell, 2019). That shift in mindset can also change academic performance and retention as demonstrated by Walton (2007, 2011), as well as how those student researchers in turn communicate science to their peers (Halliwell et al., 2020).

The model of co-creating science questions using citizen science datasets greatly improved student researchers' self confidence in asking science questions, created a sense of belonging in a science field, and shifted how student researchers think about themselves as scientists (Carpi et al., 2017). Not all citizen science projects, or research internships effectively engage student researchers or the public (Hunter et al., 2020). Citizen science allowed for discovery of science with easily accessible tools that the student researchers were confident with using and learning. Utilizing a hybrid approach to field citizen science allowed for a more robust research effort with expanded involvement. This approach presents a model for conducting more thorough research involving participants that may not otherwise be able to contribute. Such an approach can and should be considered as an aspect of citizen science design for future environmental inventory projects. Both hybrid team projects allowed the student researchers to become much more familiar with the conditions and attributes of the study region and its organisms. They were able to learn or expand new skills and begin synthesizing the possible implications of field work before they arrived in the field.

5. Conclusion

Emerging technology of the 21st century opens the doors of science inquiry to a youth population that is ever more socially connected and committed to solving problems and environmental injustices. Natural history collections, climate data and citizen science databases are increasingly robust and can be used as online tools to create virtual experiences that can be dovetailed with on-the-ground crews. Such a combination of virtual and placed-based learning may be a new potential to engage a broader audience of students in field experiences and in the environmental disciplines. The summer 2020 forced field experiences to be reimagined and the resultant successful hybrid model of the Pollinator Hotshots holds great potential. Several student members who participated in the virtual work were able to be full time employed over the summer. Other students with health or other travel restrictions were also able to participate in real time field work as crews could log in (given available cell signal) and upload data that the virtual team could see in real time: *"The part of the internship that has been most enjoyable is being able to shift what we are doing from week to week. Being able to spend a week and a half in the field and then shift to online learning helps me cope with the challenges that COVID has presented. It allows me the disconnection from the online environment I was seeking but also helps to engage my mind with the complex issues when I am home"* (Undergraduate Student, Female, Colorado). Using predictive modeling techniques combined with field verification also meant that virtual team members were able to learn how to use complex datasets such as climate data and combine those datasets with citizen science data to address the larger research questions. Based on the reflective surveys, this co-creation of research questions and data was able to keep students engaged on both virtual and in person teams over a 12-week period and in some cases all the way through to the final professional presentation in December. Because research is an ever-changing environment due to the ongoing pandemic, researchers will continually adapt fieldwork requirements, data collection, and learning objectives (Krause et al., 2021).

The Pollinator Hotshot crew is a partnership with the CO-WY AMP program so most of the students are from underrepresented groups in the sciences or are first generation. This project introduced a highly diverse student crew to complex datasets and provided them with the skills to conduct professional research online and correspond with a virtual crew. Such collaboration gave a diverse crew a sense of ownership to the project and identity as a science research team asking a question important for park management or the global community and the larger global questions (Pearson et al., 2018; Taylor, 2018). By engaging students in the co-creation and research question process while also maintaining a remote workspace, student learning outcomes translated towards broader ecological understanding that perhaps would not have occurred in an in-person space. The global environmental challenges provide a common framework where student researchers can co-create science using citizen science datasets, communicate their findings to a larger audience, and develop a sense of belonging to the global community. Communicating science that combines social elements with technology is critical so that student researchers can be agents of change in an increasing virtual global conversation needing to adapt to innovative research methods.

Data availability

All data is available through ArcGIS online and iNaturalist under Pollinator Hotshots. Datasheets are publicly available on EpiCollect5. For questions regarding data availability, please contact Sarah.Whipple@rams.colostate.edu.

Ethics and consent statement

All human subjects research was approved by Colorado State University IRB#1896. All pollinator research was approved by Yellowstone Research Permit #8080 and Grand Teton Research Permit #0025.

Authors' contributions

Sarah Whipple: Conceptualization, Validation, Investigation, Writing-Original Draft, Writing- Review & Visualization. Andrew Rohlf: Methodology, Validation, Formal Analysis, Writing-Original Draft, Data Curation. Cristal Dominguez Vasquez: Methodology, Validation, Writing-Original Draft. Daniel Dominguez: Writing-Review & Editing. Gillian Bowser: Supervision, Project Administration, Funding Acquisition. Philip Halliwell: Writing-Review & Editing, Supervision.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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