Engaging the community in pollinator research: the effect of wing pattern and weather on butterfly behavior

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Abstract

Community science, which engages students and the public in data collection and scientific inquiry, is often integrated into conservation and long-term monitoring efforts. However, it has the potential to also introduce the public to, and be useful for, sensory ecology and other fields of study. Here we describe a community science project that exposes participants to animal behavior and sensory ecology using the rich butterfly community of Northwest Arkansas, USA. Butterflies use visual signals to communicate and to attract mates. Brighter colors can produce stronger signals for mate attraction but can also unintentionally attract negative attention from predators. Environmental conditions such as weather can affect visual signaling as well, by influencing the wavelengths of light available and subsequent signal detection. However, we do not know whether the signals butterflies present correlate broadly with how they behave. In this study, we collaborated with hundreds of students and community members at the University of Arkansas (UARK) and the Botanical Gardens of the Ozarks (BGO) for over 3.5 years to examine relationships among wing pattern, weather, time of day, behavior, and flower choice. We found that both weather and wing color influenced general butterfly behavior. Butterflies were seen feeding more on cloudy days than on sunny or partly cloudy days. Brown butterflies fed or sat more often, while white butterflies flew more often relative to other butterfly colors. We also found that there was an interaction between the effects of weather and wing color on butterfly behavior. Furthermore, butterfly color predicted the choice of flower colors that butterflies visited, though this effect was influenced by observer group (UARK student or BGO participant). These results suggest that flower choice may be associated with butterfly wing pattern, and that different environmental conditions may influence butterfly behavior in wing-pattern-specific ways. They also illustrate one way that public involvement in behavioral studies

can facilitate the identification of coarse-scale, community-wide behavioral patterns, and lay the groundwork for future studies of sensory niches.

Key words

citizen science, community science, Lepidoptera, visual signaling, sensory niche, conservation

Introduction

Community science has long been used to engage the public in the scientific enterprise, raise awareness of the greater ecosystem, and collect phenological data on a scale beyond what is possible for professional scientists (reviewed in Kobori et al., 2016). In addition to providing thousands of records annually for long-term phenological monitoring efforts of numerous species (Cooper et al., 2015; Prudic et al., 2017), community scientists have often played key roles in the discovery of natural history traits and migratory patterns, as illustrated by the monarch butterfly, *Danaus plexippus* (Ries & Oberhauser, 2015). These collaborative projects between professional and amateur scientists often provide great value, both as educational tools and as a method for gathering large amounts of otherwise difficult to obtain data.

While individual projects sometimes target specific audiences, when taken as a whole community science projects have, and continue to, engage a wide range of community members. K-12 school groups and college classes catch and tag monarch butterflies (e.g., Monarch Watch, www.monarchwatch.org), monitor invasive crabs (Delaney et al., 2008), and track intertidal community diversity (Cox et al., 2012). Entire communities, children through adults, put out bird boxes or watch bird nests (e.g. Nestwatch, https://nestwatch.org/, Cooper et al., 2015), monitor sea turtle nests (e.g. Florida Statewide Nesting Beach Survey https://myfwc.com/research/wildlife/sea-turtles/nesting/monitoring/), and participate in annual bird counts (https://www.audubon.org/conservation/science/christmas-bird-count). These projects offer the public a window into the life of a scientist. Community science opportunities and inquiry-based science projects can also enhance the scientific understanding and self-confidence of participants, potentially increasing interest in careers in science (Beck & Blumer, 2012; Makuch & Aczel, 2018). However, opportunities to participate in these projects are not evenly spread across regions and communities (Pandya, 2012; Soleri et al., 2016). In the USA, many states with low college degree attainment, such as Arkansas (currently ranked 47th out of 50, U.S. Census Bureau), have high involvement in agriculture, hunting, and fishing, all of which facilitate engagement with the natural environment. One way to bridge the gap between interest in science education and engagement with the natural environment may be to engage the community in scientific projects, by reaching out to young children, college students, and other adults.

Community science can be used for both data collection and conservation efforts. Many pollinator species, including butterflies, face endangerment due to habitat loss, wildflower decline, and urbanization (Preston et al., 2012). For example, the monarch butterfly faced an 81% population decline from 1999-2010 (Pleasants & Oberhauser, 2013). Community science can be used to track these population declines and allow conservation groups to execute plans to protect and conserve at-risk populations (Ries & Oberhauser, 2015). In one such effort, the work of community scientists was critical for the identification of the preferred substrate of little terns, *Sterna albifrons*, which then led to the Little Tern Project treating colony sites with the terns' preferred substrate (Kobori et al., 2016). The app eButterfly currently utilizes community scientists to better understand butterfly distribution and abundance; this provides helpful information for conservation strategies, allowing scientists to track timing of butterfly migration and study impacts of global change on migration (Prudic et al., 2017).

Community science also encourages people to change their behavior in ways that help conservation efforts. Most community science projects in the United States have a conservation focus, and many provide volunteers with information about conservation actions they can take (Lewandowski & Oberhauser, 2016). Surveys of participants in a community science project on invasive plant species showed that 86% of participants began considering invasiveness when purchasing plants, while 70% reported changing their behavior, and 43% reported discussing invasive plant species with others (Jordan et al., 2011). Similarly, 56% of participants in Neighborhood Nestwatch, a project designed to improve knowledge about avian ecology and spread awareness for conservation initiatives, reported changing some aspect of their behavior, such as planting shrubs that could act as food or shelter for birds (Evans et al., 2005). Many participants in the Neighborhood Nestwatch study also reported that they joined in order to educate their children on conservation efforts, demonstrating that community science can be used to spread conservation awareness to younger audiences (Evans et al., 2005).

Since community science can be used to obtain widespread data and population estimates, it has often been used in ecological research, including community and conservation ecology (Bonney et al., 2009; Curtis et al., 2015; Delaney et al., 2008; Hochachka & Dhondt, 2000). Understanding species-specific niches can help predict how environmental change will affect numerous animal communities, including pollinators, and specifically butterflies. For example, increases in land use intensity result in a decrease in butterfly abundance and diversity; this can be explained by a decrease in butterfly species with narrower thermal niches and characteristics associated with specialists, such as a decreased ability to disperse and shorter flight periods (Kühsel & Blüthgen, 2015; Börschig et al., 2013). Likewise, butterfly species that are specialists in terms of host plant diet do worse with decreased host plant abundance than generalist species with similar diets (Curtis et al., 2015).

The role of variation in visual sensitivity and specialization in shaping animal community response to environmental change is less well understood, though visual niches – ambient light environments that optimize signal detection of specific wavelengths of light – have long been hypothesized to be important for habitat selection and signal evolution (Endler 1992, 1993). Animals take advantage of the visual niches created by different light conditions by evolving specific body colors and changing their behaviors to optimize signaling and signal detection (Endler, 1991; Endler & Théry, 1996). Depending on the ambient light environment, certain colors become more conspicuous and should be used for signaling, while those that are less conspicuous may be used for camouflage. For example, butterfly species who use polarized light when signaling are more likely to be found in dim forest habitats where reflected polarized light would be more conspicuous compared to bright open habitats (Douglas et al., 2007).

Variation in the visual ability of different groups of pollinators has also been used as a key component of pollination syndromes, where descriptions of flower color, shape, and odor are used to predict the type of pollinator that will visit, and pollinate, each flower (reviewed in Ollerton et al., 2009, Reynolds et al. 2009, Gong et al. 2015). Furthermore, changes in flower color have been shown to cause changes in primary pollinators (Schemske & Bradshaw, 1999; Bradshaw & Schemske, 2003). Classic pollination syndromes separate bees from butterflies due in part to the variation in bee and butterfly vision (Bernard & Remington, 1991; Peitsch et al., 1992). However, butterflies are often treated as a single class of pollinators, even though butterfly vision varies significantly across species (Stavenga et al., 2001; Stavenga, 2002; Briscoe & Bernard, 2005) and even between sexes (Everett et al., 2012; Ogawa et al., 2013). There is also evidence that butterfly species are adapted to specific visual niches (Douglas et al., 2007, Frederiksen & Warrant, 2008; Montgomery & Merrill, 2017; Montgomery et al., 2021) and changes in ambient light could have serious implications for butterfly conservation (Seymoure, 2018).

Species of butterflies appear to partition their habitat based on light environment in ways that correspond to visual ability or signal color (Estrada & Jiggins, 2002; Douglas et al., 2007; Cheng et al., 2018; Montgomery et al., 2021). The high diversity of butterflies we see in habitats with many local light environments (small pockets of shade or full sun, for example) may be associated with visual niche partitioning, where different species utilize different light environments or color-spaces for signaling and signal detection (Endler, 1992, 1993). Butterflies have species-specific preferences for both flower colors when nectaring and wing colors when looking for mates (Jiggins et al., 2004; Kronforst et al., 2006; Pohl et al., 2011). Since variation in butterfly visual sensitivity is coarsely associated with variation in butterfly wing pattern (Stavenga et al., 2001; Briscoe et al., 2010; Everett et al. 2012), comparing the colors of flowers visited by different colored butterflies is a first step toward assessing whether butterflies are partitioning food sources in a color-dependent way at a community scale. While other floral traits, such as shape, odor, and amount of nectar reward may also be important components of flower selection (Corbet, 2000; Tang et al., 2013), butterflies use ~ 2/3 of their brains to process visual information (Snell-Rood et al., 2009; Heinze & Reppert 2012). Thus, visual information is likely to be particularly important for flower selection by butterflies. This type of observational study may also encourage the public to consider pollinator diversity and the value of maintaining this diversity in the context of flower abundance and pollinator-dependent crops.

To assess whether wing color (coarsely defined) is predictive of butterfly flower choice, activity, and abundance in different weather conditions, and to improve engagement with the greater Northwest Arkansas (NWA) community and expose college students to field research, we developed a Community Science/Undergraduate Research project that examined the behavior of native butterflies in Northwest Arkansas. In collaboration with the Botanical Gardens of the Ozarks (BGO), we designed a project that could be conducted by students of all ages, both individually and with family, friends, or school groups. Through this activity, we intended to increase awareness of the diversity of pollinators in NWA, expose undergraduate students to field observation, strengthen the bonds between local non-profit organizations and the University of Arkansas, and collect data that could be used to spearhead future studies on sensory niche partitioning and pollinator conservation. While surveying wing colors with human observers is limited by the fact that human color vision differs from that of butterflies, particularly in our inability to see ultraviolet and polarized light (Arikawa et al., 1987; Schnapf et al., 1987; Reppert et al. 2004; reviewed in Stavenga & Arikawa, 2006), such surveys are a first step toward identifying the presence of visual niches at the butterfly community level. Our study's design allows for large amounts of data collection that can direct future targeted quantitative studies of butterfly community wing color and behavior.

With this study we examined if there was evidence of butterflies partitioning color-space (visual niches) in the NWA area by assessing the relationship between butterfly wing color and butterfly flower color preference, as well as the effect of cloud cover and time of day on observed butterfly color, butterfly behavior, and flower color preference. If different species of butterflies preferentially visit different flowers in a color-specific way, we might expect to observe one of a few different outcomes. 1) Butterflies might preferentially visit flowers they match in color, either due to sensory bias for that color (Endler & Basolo 1998; Fuller et al., 2005), or because it decreases detectability by predators (Shreeve, 1990). In this scenario we would expect yellow butterflies to be seen more on yellow flowers, purple butterflies on purple flowers, white butterflies on white flowers, etc. We assume there will be some undercounting of butterflies on color-matched flowers due to camouflage and detection bias; however, the large size of most butterflies relative to the flowers they visit in NWA should allow us to detect color-matching if it occurs. 2) Butterflies might instead prefer flowers of colors they associate with either particular nutrients or honest signals on the wings of potential mates. This would result in our observing different species (and colors) of butterflies preferentially visiting different flowers in a color-specific way, though in a less predictable fashion than with color-matching. 3) If butterflies do not exhibit species or color-specific preference for different colors of flowers, we would expect to see all butterflies visiting similar colors of flowers independent of butterfly color, and most likely visiting the colors of flowers attributed to attract butterfly pollinators in pollination syndromes: vivid red, yellow, or blue (Ollerton et al., 2009). 4) We also predicted that some colors of butterflies, such as white, which reflect short wavelengths of light (including UV), would be observed to be more active and abundant on cloudy days compared to sunny days, as the relative amount of short-wavelength and long-wavelength light in the environment changes with cloud cover (reviewed in Calbó et al., 2005).

Methods

Study species: Participants surveyed butterflies from across NWA. Because butterflies were identified by color rather than species (partially as an effort to engage participants with limited knowledge of butterfly species), we do not know the exact species included. However, based on colors and sizes reported by participants, and species lists for the area, some likely species include *Danaus plexippus* (monarch), *Papilio glaucus* (Eastern tiger swallowtail), *Junonia coenia* (common buckeye), *Strymon melinus* (gray hairstreak), *Vanessa virginiensis* (American lady), *Vanessa cardui* (painted lady), *Chlosyne nycteis* (silvery checkerspot), *Physciodes tharos* (pearl crescent), *Colias philodice* (clouded sulphur), and *Colias eurytheme* (orange sulphur), in addition to many others.

Study sites: One of our primary sites was the Botanical Garden of the Ozarks (BGO), Fayetteville, AR (36º08'12"N and 94º07'06"W, Figure 1A). The BGO is 44 acres in size, has twelve themed gardens, and contains a native butterfly house. There are an estimated 80,000 visitors every year, and an average of 18,000 people per year are educated about butterflies and pollinator gardens through the BGO's various programs. University of Arkansas (UARK) Animal Behavior students made their observations at a second site, Wilson Park, Fayetteville, AR (36°04'22.8"N 94°09'48.0"W) from 2017-2019. Wilson Park is a 22.75-acre park located in the center of Fayetteville, AR. Wilson Park has a spring, pond, playground, and walking trail. Additional study areas included various locations throughout NWA and the greater region where UARK Principles of Zoology students conducted their observations. Principles of Zoology students were not given a specific location to conduct observations, and conducted their surveys in residential neighborhoods, farms, city and state parks, and wilderness areas throughout the region. Most students recorded the latitude and longitude of their starting point (Figure 1). Animal Behavior students in 2020 also conducted their butterfly surveys throughout the region due to COVID shutdowns at UARK, and reported their survey locations (Figure 1). Northwest Arkansas is composed of wet and dry prairies and the Boston Mountains.

Experimental design: Observations were collected by NWA community members at the BGO and UARK students enrolled in Principles of Zoology and Animal Behavior over a duration of 3.5 years, from April 2017 to November 2020. Animal Behavior students, Principles of Zoology students, and Botanical Garden visitors were asked to collect similar observational data but were given different instructions concerning the duration of their survey. Participants were instructed to note date, time, color of the butterfly, activity of the butterfly (flying, feeding, sitting), size of the butterfly (small, medium, large), and color of the flower the butterfly was on if it was on a flower. To reduce participant subjectivity we defined small as butterflies that were the size of a "pencil eraser to watch face, or slightly bigger", medium as "about the size of a key", and large butterflies as "bigger than a key". Color is in principle less subjective than size, but can be somewhat subjective in practice, particularly given that a small number of our participants (roughly 1-5% given the male:female ratio of participants) are likely to be red-green colorblind. However, given the high numbers of participants, and use of multiple study locations and data collected over multiple years, the participation of a small number of colorblind individuals should not significantly skew our results. We did not ask participants to try to identify species because we wanted students of all ages (3 and up) to be able to participate in this activity and felt that species identification might be a barrier to young children or those less familiar with butterflies – two of the groups of people we were most interested in engaging. However, by examining the effect of wing color and wing color-size interactions we can still determine if it is likely that visual niches, which may be associated with butterfly family (Pohl et al., 2009; reviewed in Stavenga & Arikawa, 2006), are widespread enough across the NWA butterfly community to be detected by amateur scientists.

In addition to individual participants at the BGO, the director of education built the community science project into the field trips she conducted so that student groups participated as well as individual visitors. Upon arrival at the garden, children were empowered to take on the role of community scientists. Teachers or volunteer docent guides were given the tally sheet (for survey sheet see Supplemental Figure 1), and students were told to look for butterflies and report their findings to their teacher or volunteer docent guide. Most students appeared to take great pride in participating in a scientific research project, and teachers reported that students gained observational skills through the project. In some cases, volunteers had to ask students to stop counting butterflies, because the students were so focused on the community science project that they did not want to move on to the next task.

Principles of Zoology and Animal Behavior students were asked to record weather conditions (sunny, cloudy, partly cloudy, rain) in addition to butterfly data. This allowed us to qualitatively track relative amounts of UV in the environment, since cloudy days have relatively higher proportions of UV than sunny days, and partially cloudy days have intermediate amounts of UV relative to cloudy and sunny days (reviewed in Calbó et al., 2005). Participants were instructed to pick one main color for the butterflies and the flowers. In Principles of Zoology, students were asked to collect butterfly observation data over a 30-minute walk during a 7-10 day period in the last week of September and first week of October (for survey sheet see Supplemental Figure 2). Observations were collected on paper and submitted in class. For Animal Behavior, students went on a 30-minute walk at Wilson Park on the Friday closest to April 16. Observations were completed in groups and collected on paper (Supplemental Figure 3). In 2020, due to COVID shutdowns, students went for a 30-minute walk on their own wherever they were located, instead of as a class (for survey sheet see Supplemental Figure 4). Botanical Garden participants were not given a time limit and collected data throughout the year (for survey sheet see Supplemental Figure 1). Data from all participants were compiled into an Excel spreadsheet for analysis.

To reduce the likelihood of data falsification, all undergraduate participants were told repeatedly that the lack of butterflies on a walk was also important to report, both in individual correspondence and in class-wide discussion. Full credit for the assignment was given for turned in data sheets, regardless of the numbers of butterflies observed on the sheet. Visitors to the BGO were also encouraged to report zeros if they did not see any butterflies on their walk through the garden. Sheets had space for 23 butterfly entries. Half sheets that had space for 6 butterfly entries were also available at the BGO, as they were easier for the small hands of young children to hold and fit on small clipboards purchased specifically for this project.

Post-activity assessment: Formal post-activity assessment occurred in Principles of Zoology 2018-2020. For both Animal Behavior and Principles of Zoology, class data were analyzed and presented to the students at the end of the semester in the context of regional weather data and in comparison to data from past years, the other course, and the BGO. Due to the nature of final exams in these two courses, students in Principles of Zoology but not Animal Behavior were asked about what they learned from the project and in-class discussion in an open-response question on the final exam. Informally, a number of students in both classes volunteered comments, either verbally or via e-mail, about the value of the activity. We did not ask BGO participants to complete a post-activity survey, as we felt that might reduce interest in activity participation, though we are making data and results available to teachers of the classes that participated in the project so they can use it for assessment if they would like.

Data processing: After all data were entered, we separated butterfly colors into the most likely main color or colors because sometimes (18% of records) participants picked more than one color. For consistency, one researcher reclassified all butterfly colors for these records and used the color combination reported plus the size to identify the most likely main color based on the butterfly species list for NWA. For example, 109 butterflies were reported as blue/black. We classified all blue/black butterflies as black because the iridescence of scales on local species of swallowtails causes them to appear blue or black to people based on the angle of the sun relative to the viewer. The original classifications for all butterflies can be found in the data file on Dryad. Main colors were designated prior to conducting analyses and without looking at the behaviors, weather, flower choice, or time of day recorded for each butterfly to reduce the possibility of bias in analyses associating butterfly color with butterfly behavior.

We filtered out rare responses in the following ways: For analyses involving butterfly color, we removed all colors with less than 1% responses, leaving us a subset including the butterfly colors yellow, black, blue, brown, orange, and white. For analyses involving size, we removed the few observations (27, 0.7%) where participants selected multiple sizes. For analyses involving activity, 3% of butterfly records had more than one behavior recorded. For 80 of these butterflies feeding was selected along with an additional behavior. We categorized feeding as the dominant behavior for these butterflies, because butterflies feed when either flying or standing/sitting on a plant, and we were interested in assessing which butterflies were observed feeding relative to not feeding while stationary or not feeding while flying. Since we did not ask participants to record whether feeding butterflies were sitting or flying, we did not have enough data to assess whether feeding butterflies were observed more often flying or sitting. Only 1%

(42 butterflies) were recorded as both flying and sitting, and we excluded these records due to insufficient data for analysis as a separate behavioral category. For analyses involving weather, we created a subset containing sunny, cloudy, and partly cloudy weather, as those were the predominant selected weather options (responses of rainy, cold, warm, and specific temperatures were rare). For analyses involving flower color, we created a new category, “multi” for the records where multiple colors were selected, giving us the final options of blue, green, orange, pink, purple, red, yellow, white, and multi. We acknowledge that reports of green may indicate a butterfly on a part of a plant that was not a flower, or a butterfly visiting a plant with small flowers or flowers of colors that were difficult to detect against a green background. We first subset by class, then weather, then time, then butterfly color, then butterfly size, and finally by flower color or butterfly activity. Data were subset by class first for the chi-square analyses, and then by whichever variables we were using for that test. For nominal logistic regression models, subsets were made using the same methods; however, class was always subset last. For analysis of demographic information, BGO volunteers were categorized as “Children” (under 18) or “Adults” (18 or older). Children ranged in age from 3 -17. Sheets filled out by ages from both categories were excluded from demographic analysis. Student observations from the Principles of Zoology and Animal Behavior courses were combined into a “Student” category.

Maps: All maps were produced in QGIS 3.6. A detailed pipeline can be found in Supplemental Materials.

<u>Statistical analysis:</u> All analyses were conducted separately for BGO participants and UARK students, except for those testing the effect of demographic (child, student, adult) on observations. For analyses using weather as a factor, only data collected by UARK students were used because BGO participants did not report weather conditions. To determine if butterfly size or color affected observed activity or the colors of flowers on which butterflies landed, we conducted chi-square tests. We also assessed the effect of weather, time of day, and survey year on observed butterfly color, size, and behavior using chi-square tests.

To account for correlative effects of butterfly color and size, and to test for any interactive effects of butterfly color and weather, we conducted a series of nominal logistic regression models (NLM) with butterfly activity, flower color, butterfly color, and butterfly size as dependent variables; and butterfly color, butterfly size, weather, time of day, and a number of interaction terms as factors (Table 1).

We ran chi-square tests to see if “Student”, “Child”, or “Adult” status affected the reported size, color, or activity of observed butterflies. We also ran tests to see if there were differences in the sizes and colors of observed butterflies across years.

Since we conducted 21 chi-square tests for UARK data and 17 chi-square tests for BGO data, we used a Bonferroni corrected p-value of 0.002 for our chi-square tests using UARK data and a corrected p-value of 0.003 for BGO data. We conducted 10 nominal logistic regression models using UARK data, and 3 nominal logistic regression models using BGO data, and used a corrected p-value of 0.005 and 0.017 respectively for these models. All chi-square analyses and demographic analyses were conducted in R 4.0.0, and all nominal logistic models were conducted in JMP Pro 15. Supplemental Figure 5 was created using 'ggplot2' and 'ggpattern' packages in R (Wickham, 2016; FC, 2020).

Ethical statement: No butterflies were harmed during this study; all observations were no-contact. No humans were harmed in the conducting of this experiment; UARK students participated in this as part of their class requirements and BGO participants were either volunteers or members of class groups.

Results

Survey participant demographics and butterfly summary statistics

During the 3.5 years we worked with the BGO, Principles of Zoology students, and Animal Behavior students, we had an estimated 1,080-1,480 participants (assuming school groups containing 10-20 students, and some repeat participants) (Supplemental Table 1). When combining all 4 years and both BGO and UARK participants, the month with the most surveys was October (159, Supplemental Figure 5 A, B), and year with the most surveys (225) was 2017.

Participants observed 3,916 butterflies total; BGO visitors observed 2,083 of these butterflies, Principles of Zoology students observed 1,702 butterflies, and Animal Behavior students observed 131 butterflies. The most common color reported was orange, the most common size small, and the highest monthly average of butterflies observed per survey sheet (16.5) occurred in August 2019 (Supplemental Figure 5C,D). See Supplemental Results for details.

Effect of participant type (child, college student, adult) on data collection

When the full data set was analyzed, the age class of participant (child, adult, or college student) had a significant effect on observed butterfly size, butterfly color, and butterfly activity: children reported seeing more medium butterflies than adults or students; adults and children reported seeing more black and blue butterflies than students; and adults reported seeing more feeding butterflies than children or students (Table 2, Figure 2A, C, E). However, when college students' observations were only compared to observations of BGO participants that were recorded during the same months as the college student surveys (April, September, and October), we only retained an effect of participant age on observed butterfly color (Table 2, Figure 2D), with adults seeing more blue butterflies than children or students. There was no longer an effect of age on observed butterfly size or butterfly activity (Table 2, Figure 2B, F).

Effect of butterfly color and size on butterfly behavior

Butterfly color was correlated with butterfly behavior in data collected by BGO participants and UARK students (Table 3, Figure 3B,E). At BGO, white butterflies were seen flying more than feeding or sitting, while brown butterflies were seen feeding more than sitting or flying. UARK students saw brown butterflies sitting more than feeding or flying. Butterfly size was correlated with butterfly behavior in BGO but not in UARK data (Table 3). However, butterfly size was correlated with butterfly color in both the BGO and UARK data. Black butterflies were more likely to be large than small or medium, and brown and white butterflies were more likely to be small (Figure 3A,D). At the BGO, when butterfly color, butterfly size, and an interaction term of butterfly color and size were included in a NLM, we found that only butterfly color and the interaction term significantly influenced activity, suggesting butterfly color may be more important than butterfly size in predicting butterfly behavior (butterfly color: $\chi2$=93.971, P<0.0001; butterfly size: $\chi2$=12.651 P=0.0131; butterfly color*butterfly size: $\chi2$=43.242, P=0.0019; n=1,933). From data collected by UARK students, we found that only butterfly color significantly influenced activity (NLM, factor effects: butterfly color: $\chi2$=29.436, P=0.0011; butterfly size: $\chi2$=7.191, P=0.1261; butterfly color*butterfly size: $\chi2$=31.100, P=0.0539; n=1,751).

Effect of butterfly color, butterfly size, and weather on flower choice

Main butterfly color was predictive of the color of the flower on which butterflies were seen in both BGO and UARK data (Table 3, Figure 3C,F). White butterflies were seen on green flowers more than the other colors of butterflies at the BGO. Weather also influenced the color of flower on which a butterfly was seen (Figure 4C). Butterflies were seen on orange and red flowers more often on cloudy days than in other weather conditions, and on multicolor flowers more often on partly cloudy days than in other weather conditions.

Butterfly size influenced flower color chosen at the BGO, but not in UARK data (Table 3). Large butterflies were seen on orange flowers more than the other sizes of butterflies at the BGO. There was an interactive effect of butterfly color and size on flower color choice at the BGO (NLM, factor effects: butterfly color: $\chi2$=78.013, P=0.0003; butterfly size: $\chi2$=32.734, P=0.0080;

butterfly color*butterfly size: $\chi 2=135.793$, $P<0.0001$; n=1,252); but not in UARK data (butterfly color: $\chi 2=70.164$, $P=0.0022$; butterfly size: $\chi 2=148.124$, $P<0.0001$; butterfly color*butterfly size: $\chi 2=67.464$, $P=0.8401$; n=876). After controlling for weather, we lost the effect of butterfly size on flower color choice (NLM, factor effects: butterfly color: $\chi 2=291.738$, $P<0.0001$; butterfly size: $\chi 2=18.693$, $P=0.2849$; weather: $\chi 2=89.518$, $P<0.0001$; weather*butterfly color: $\chi 2=89.518$, $P=0.2187$; butterfly color*butterfly size: $\chi 2=61.439$, $P=0.8081$; n=605).

Effect of weather on butterfly color, butterfly size, and butterfly behavior

Because BGO participants were not asked to note weather conditions, effects of weather were only analyzed using UARK data. Weather affected observed butterfly behavior (Table 3, Figure 4). Butterflies were seen feeding more on cloudy days than during other weather conditions. However, weather did not have a significant effect on either observed butterfly color or observed butterfly size. When weather, butterfly color, and an interaction term were used as factors in a NLM, we found that only butterfly color and the interaction term affected butterfly behavior (weather: $\chi 2=12.252$, $P=0.0156$; butterfly color: $\chi 2=35.247$ $P=0.0001$; weather*butterfly color: $\chi 2=46.842$, $P=0.0006$; n=1,239). When weather, butterfly size, and an interaction term were used as factors, we found that none of these variables influenced butterfly behavior (weather: $\chi 2=9.801$, $P=0.0439$; butterfly size: $\chi 2=11.042$, $P=0.0261$; weather*butterfly size: $\chi 2=19.494$, $P=0.0124$; n=1,248; Bonferroni adjusted significant p-value =0.005).

Effect of time of day on butterfly color, butterfly size, and butterfly behavior

Time of day had an effect on observed butterfly color in both BGO and UARK data (Table 3). Orange butterflies were seen more in the evening than the other colors of butterflies. Time of day also had an effect on observed butterfly behavior in BGO data, but not in UARK data. At the BGO, butterflies were seen feeding more in the morning than the other times of day. A NLM with the variables time, weather, and an interaction term between time and weather showed that only the interaction term affected butterfly color (Supplemental Table 3). A NLM with the variables time, weather, and an interaction term between time and weather showed that none of these variables had an effect on butterfly behavior or butterfly size (Supplemental Tables 2, 4).

Effect of butterfly color, butterfly size, time, and weather on butterfly behavior

A NLM with the variables butterfly color, butterfly size, time, weather, and an interaction term of weather and butterfly color showed that only butterfly color and the interaction term affected butterfly behavior under our Bonferroni correction (butterfly color: χ2=31.252, P=0.0005; butterfly size: χ2=4.270, P=0.3706; time: χ2=9.779, P=0.0443; weather: χ2=13.941, P=0.0075; weather*butterfly color: χ2=58.270, P<0.0001; n=1,106).

Post-activity Assessment

Of the 163 Principles of Zoology students who took a final exam in the course from 2018-2020, 93.8% accurately described a finding from the analysis of their class butterfly data, with most mentioning effects of weather, butterfly wing color, and morphology associated variance in butterfly behavior (Figure 5).

Discussion

By coordinating with a local not-for-profit and students from two college courses, we were able to introduce 678 individuals as well as 40 large school groups (~ 400-800 students) to sensory ecology and pollinator biology. Participants recorded the behavior of just under 4,000 butterflies and did not appear to have a detection bias for large butterflies, as more small butterflies than large butterflies were reported by all age classes. Participants did not report large numbers of red butterflies, or higher proportions of orange or yellow butterflies against green backgrounds, which we may have expected given that human vision is especially tuned to red and yellow objects on green foliage (Párraga et al., 2002). Observers reporting a lower percentage of black butterflies on green foliage may be a reflection of detection bias, however, as black is harder for humans to detect against green (Bhattacharyya et al., 2014; Zhang et al., 2017). Using this large data set, we found that coarse descriptions of butterfly wing color were predictive of butterfly flower color choice, as well as butterfly abundance and activity in different weather conditions. While these coarse descriptors of butterfly behavior and identity (size and color) do not allow us to definitively address the presence of visual niches in the butterfly community of North American prairies, they do provide preliminary data for a number of future research directions. Further investigation of visual niches focusing on polarized light and wavelengths of light visible to butterflies but not people, such as UV light, may be particularly illuminating, as would an exploration of the relationship among sexual dimorphism in wing pattern and sexual dimorphism in flower choice or preferred weather conditions for flight or feeding behavior. Additionally, broadly examining the relationship between flower color, nectar availability, and butterfly flower preferences may assist in predicting butterfly behaviors and understanding mechanisms for plant-pollinator interactions at the community scale.

Throughout the duration of this project, we had moderately high participation by individuals of a wide range of ages, giving multiple age groups the opportunity to become engaged in information on butterfly abundance, diversity, and behavior. This exposure can allow for participants to become involved in conservation efforts designed to protect butterflies. Other studies have found that community science projects succeed in sparking interest in conservation efforts because participants receive hands-on experience and better understand the need for such efforts (Beck & Blumer, 2012; Aristeidou et al., 2020; Evans et al., 2005). We had similar outcomes in our study: as community members became more aware of butterflies, they often sought out information on conservation efforts. Through classes, pamphlets, and signs at the BGO, guests who were drawn in through their participation in the community science project were educated about the importance of pollinator gardens as well as how to grow them. Pollinator gardens, even when designed purely for the aesthetic pleasure of viewing native butterflies, increase the diversity and population of a wide range of arthropods, which in turn feed birds, reptiles, and amphibians (Levé et al., 2019). Therefore, wider conservation efforts are made successful by focusing on charismatic butterflies to educate the community.

Involving members of the community of all ages with butterfly data collection can be useful for identifying high-impact conservation measures in addition to garnering interest in conservation (Kobori et al., 2016). From data gathered by community scientists, we saw that some butterfly colors were observed more in certain years and less in others, which could indicate interannual cycles of abundance, or a possible decline in the abundance of some species. Interannual cycles of abundance can also be an indicator of the effect of climate change on pollinator species, information that can be useful for conservation efforts (Ogilvie et al., 2017). Additionally, our results suggest that butterfly color influences the color of flower on which a butterfly will be seen. Other community science projects have been used to identify species substrate preference for future species protection and provision (Kobori et al., 2016). Linking flower color with butterfly color may be useful for indicating which flower species to protect and keep in abundance to attract and maintain a rich pollinator community. While we asked participants to report butterfly color instead of butterfly species to encourage participants from a wide range of ages and expertise, butterfly color does coarsely correlate with butterfly family (Wijnen et al., 2007; Stelbrink et al. 2019; Spencer & Simons, 2014), providing us with some general information on butterfly diversity.

Student Engagement

While a class assignment and required for Animal Behavior and Principles of Zoology students at UARK, many students expressed interest in the project in a variety of ways. First, over 90% of the students tested on the material retained information from the class discussion of this project a week later. Most of these students mentioned learning about either diversity in butterfly behavior or effects of weather on behavior, suggesting that students learned the two main educational themes of the study – that all butterflies may not behave the same, and that weather, or environmental conditions in general, may influence animal behavior. Second, numerous students made a point to mention their appreciation for being asked to go outside, look at their environment, and engage with nature in voluntary communication with their professor. This was particularly common in Spring and Fall 2020, when students were taking classes remotely due to the pandemic. Finally, at least 6 of the students who participated in this study went on to conduct intensive undergraduate research experiences working with Lepidoptera and behavior, representing roughly a third of the undergraduates who have conducted undergraduate research projects in integrative animal behavior at UARK over the last five years. For example, one of our authors was a former survey participant who became involved in this research through their Principles of Zoology class. This research has made a large impact on their career and academic interests, as inquiry-based learning projects have been shown to do for other students (Beck & Blumer, 2012). This was the first real research project the author had been a part of, and gave them insight on research methods, a previously reported benefit of inquiry-based learning (Aristeidou et al., 2020). This personal experience of one of the hundreds of students engaged in our project is an example of how community science has the potential to draw people's attention to scientific research and topics they were previously unfamiliar with, as well as to educate them on scientific reasoning and methods (Aristeidou et al., 2020).

Testimony from Director of Education and Community Outreach at the BGO

In addition to the quantifiable aspects of this study, the Director of Education and Community Outreach at the BGO (co-author Imrie) personally witnessed a wide range of people take three impactful steps toward purposeful conservation efforts. First, she witnessed genuine awe and wonder as guests who may have just walked quickly through the garden were asked to slow down and take note of the butterflies they saw. While making community science observations, they became more aware of the greater biodiversity of the garden as a whole and were driven to ask why the Botanical Garden contained more diversity than their own home garden. This led them to seek out more information, by asking questions, reading signs, or picking up free available literature. Finally, over the years, she has observed students and their families return to the garden for events, programs, or classes and tell her how they planted a garden for the first time or enhanced a garden space with more natives to help increase the butterfly diversity and population. As she witnessed these transformations in a sample of community members, she knew that our impact was much greater than she was personally witnessing.

Scientific value of butterfly behavior community science

Our finding that participants observed butterfly color to be predictive of associated flower color is intriguing, particularly considering participants did not observe an association that matched the expectations of human visual tuning. Little is known of how flower color preference relates to wing color preference, an important component of mate choice in butterflies (Jiggins et al., 2004; Kronforst et al., 2006). Visual sensitivity to color varies significantly among butterfly species, which often vary dramatically in wing color (Stavenga, 2002; Briscoe & Bernard, 2005). Participants only recorded main wing color in our study, but even small changes in wing pattern can correspond to changes in visual sensitivity to wavelengths of light and preferences for green vs. brown backgrounds (Briscoe et al., 2010; Everett et al., 2012, van Bergen & Beldade, 2019). Preference for flower color varies among species of butterflies (Pohl et al., 2011), and main wing color corresponds broadly to butterfly family for many butterfly species (Wijnen et al., 2007; Stelbrink et al. 2019; Spencer & Simons, 2014). Future studies should examine how visual sensitivities and flower preference vary within family, and how inter-family differences in visual abilities correspond to flower choice.

An understanding of how visual niche shapes the community composition and abundances of highly visual animals such as butterflies is important for their conservation. Identifying visual specialists within communities can help target at-risk butterfly species. Specialist butterfly species do worse that generalists when habitats become less diverse and more intensely used by humans (Curtis et al., 2015; Kühsel & Blüthgen, 2015; Börschig et al., 2013). Tropical butterfly species that reflect polarized light are more likely to be found in dim forest light conditions where polarized light is a better signal than bright colors, rather than in bright open spaces (Douglas et al., 2007). Additionally, studies on individual species have shown that butterflies change their behavior toward conspecifics under different light conditions, significantly increasing or decreasing courtship depending on the species and wing color preference (McDonald & Nijhout, 2000; Obara et al., 2008). In our study we also found an effect of light environment on butterfly behavior and wing color. Loss of canopy cover, shifting weather patterns due to climate change, and increased artificial nocturnal lighting will alter the light environments butterflies encounter. Unfortunately, little is known about how temperate butterflies adapt to changes in light environment. Our study harnesses the power of community science to engage the public while providing a large quantity of data that can inform future research on visual niches within temperate butterfly communities.

Our data will also be used to inform future community engagement and outreach efforts at the BGO. By sharing the scientific questions we explored through our community science/undergraduate research project, we hope to garner enthusiasm for future participation in butterfly research and butterfly conservation. Project expansions may include asking BGO participants to report weather conditions or if butterflies were seen in shade or bright sunlight. Efforts are also underway to provide garden members and K-12 students opportunities to participate in research projects from home. These efforts were initiated due to the COVID pandemic and our transition to virtual data recording options, and due to positive feedback, are likely to continue even when high involvement at the physical BGO resumes.

Future Directions

Our project was successful in engaging hundreds of college students and members of the public in gathering scientific information and observing wild animals in their community. Their efforts provided a large amount of data on the role wing color and size may play in determining the general behavior of animals in pollinator communities. The results of this study indicate that wing color, weather, and time of day can be predictors for butterfly behavior and flower choice. Wing color and butterfly size are correlated, but butterfly size cannot be predicted by weather or time of day. Our data subsequently suggest butterflies may be occupying separate visual niches; understanding these niches may be useful for future conservation efforts and butterfly research in general. These results show that community science can be used to collect large amounts of behavioral data over a widespread area, and community science projects are effective at gathering participation from all age groups. Three factors that we think enhanced the success of our project and might be useful for future scientists designing community science projects are: 1) working closely with the education coordinator at the BGO to design a project that would be accessible to young children and fun for adults; 2) emphasizing the importance of recording the absence of animals when conducting surveys; and 3) being willing to make small adjustments to the task for each demographic group (small clipboards for small hands, for example). We hope that sharing the success of this project with students and BGO visitors will encourage future participation and foster public enthusiasm for science and pollinators. We further hope that the success of this project will inspire fellow scientists to initiate and engage in community science.

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Data Availability Statement

The data underlying the article are available in Dryad Digital Repository at https://doi.org/10.5061/dryad.kkwh70s53.

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Figure legends

Figure 1: Community science butterfly data collection. A) Survey locations in Northwest Arkansas (NWA), including the BGO (red star) and Wilson Park (orange star). B) All survey locations, including those outside of NWA.

Figure 2: Effect of participant age on data recorded. When data records were compared by participant age across the full data set, there was an effect of participant age on butterfly size (A), butterfly color (C), and butterfly behavior (E). However, when data for only the months when both college courses and BGO participants were recording data (April, September, and October), there was only an effect of participant age on butterfly color, with adults seeing proportionally more blue butterflies than children or college students (D). There was no longer an effect of participant age on butterfly size (B), or butterfly behavior (F).

Figure 3: Butterflies of different colors exhibited different behaviors and flower color preferences. A-C BGO data. A) Mosaic plot of proportion of butterflies of each color by size. More black butterflies were large than were small or medium. B) Proportion of butterflies of

each color by activity. Brown butterflies were observed feeding more often than flying or sitting. C) Flower color by the color of butterfly on that flower or plant. White butterflies were found on green plants more often than other butterflies, and brown butterflies were found more often on yellow flowers. D-F University of Arkansas data. D) Proportion of butterflies of each color by size. More white butterflies were small than were medium or large. E) Proportion of butterflies of each color by activity. Brown butterflies were observed sitting more often than feeding or flying. F) Flower color by the color of butterfly on that flower or plant. Orange butterflies were found on yellow flowers more often than other butterflies, and brown butterflies were found more often on green plants.

Figure 4: Effects of weather on butterfly behavior. A) Mosaic plot of butterfly color by weather. Proportionally more brown butterflies were observed on cloudy days than on sunny days. B) Butterfly activity by weather. Feeding was observed more often on cloudy days than on sunny days. C) Flower color choice by weather. Butterflies were found more often on green plants on sunny days than cloudy days, and more often on red and orange flowers on cloudy days than on sunny days.

Figure 5: Distribution of student responses to post-survey assessment. Counts of the different types of correct answers provided by Principle of Zoology students in 2018-2020 to an open response question asking students what they learned from the project and in-class discussion. The category “butterflies behave differently” includes responses about effects of butterfly color and butterfly size on butterfly behavior.

Table 1: List of nominal logistic regression models conducted to examine the effects of butterfly color and size, as well as interactive effects of color and weather, on butterfly activity, abundance, and flower color choice.

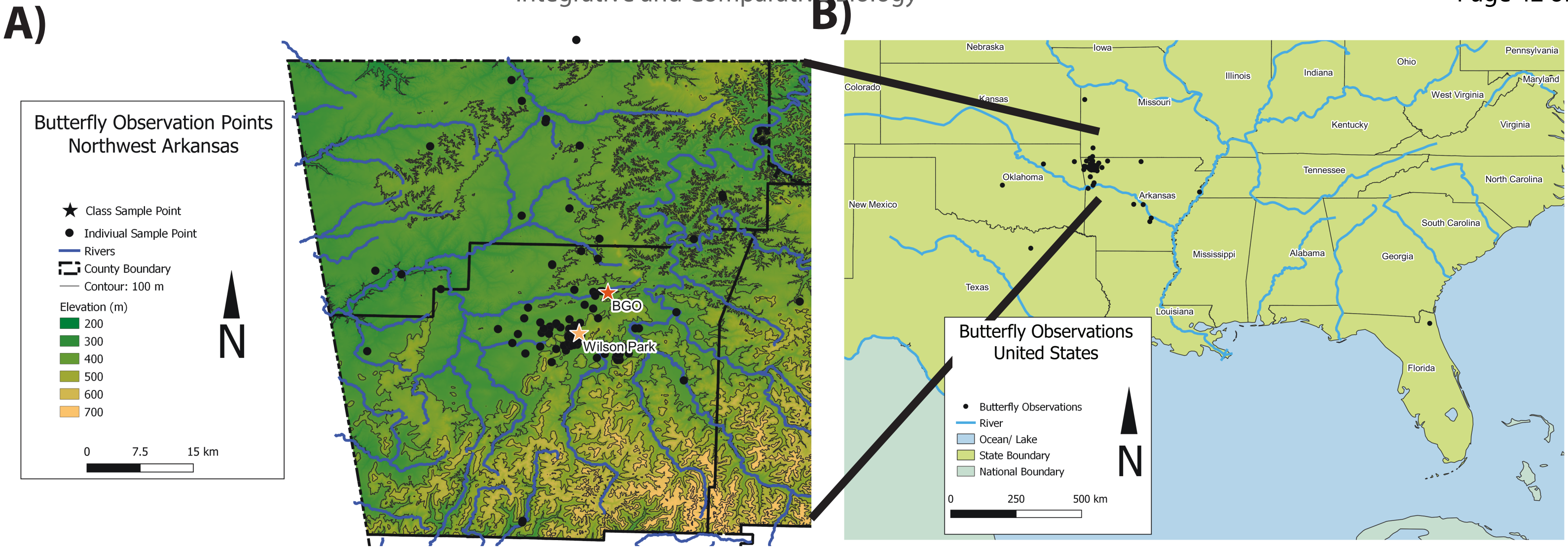
Model #	Dependent variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
1	Butterfly activity	Butterfly color	Weather	Butterfly color *Weather		
2	Butterfly activity	Butterfly size	Weather	Butterfly size* Weather		
3	Butterfly activity	Butterfly color	Butterfly size	Butterfly color*size		
4	Butterfly activity	Butterfly color	Butterfly size	Weather	Butterfly color*Weather	
5	Butterfly activity	Butterfly color	Butterfly size	Weather	Time of day	Butterfly color*Weather
6	Butterfly activity	Weather	Time of day	Weather*Time of day		
7	Butterfly color	Weather	Time of day	Weather*Time of day		
8	Butterfly size	Weather	Time of day	Weather*Time of day		
9	Flower color	Butterfly color	Butterfly size	Butterfly color*size		
10	Flower color	Butterfly color	Butterfly size	Weather	Butterfly color*Weather	

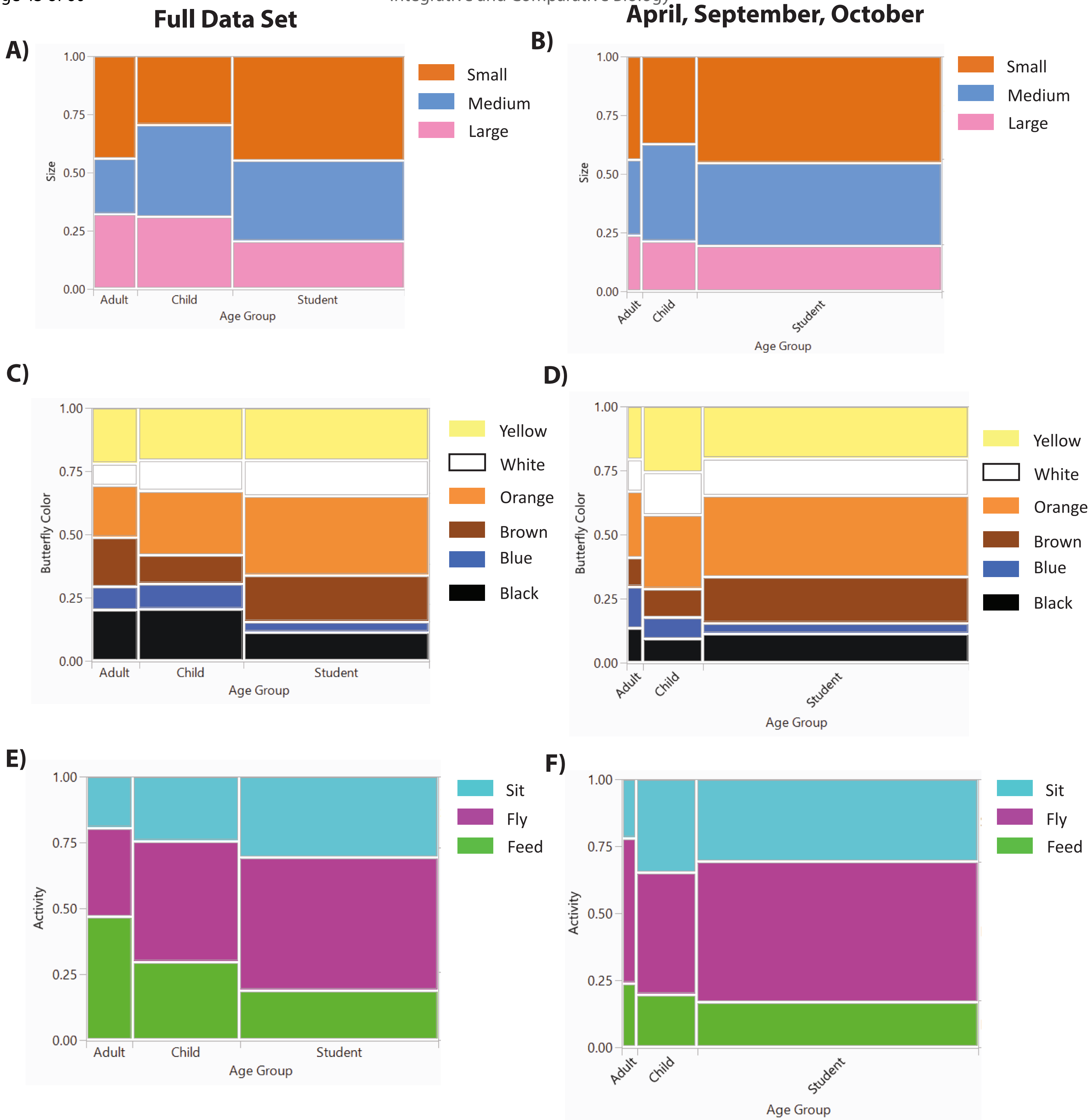
Table 2: Effect of participant type depends on time frame used in analyses. Chi-squared analyses assessing the effect of participant type (child, college student, adult) on butterfly observations. Results in bold are statistically significant.

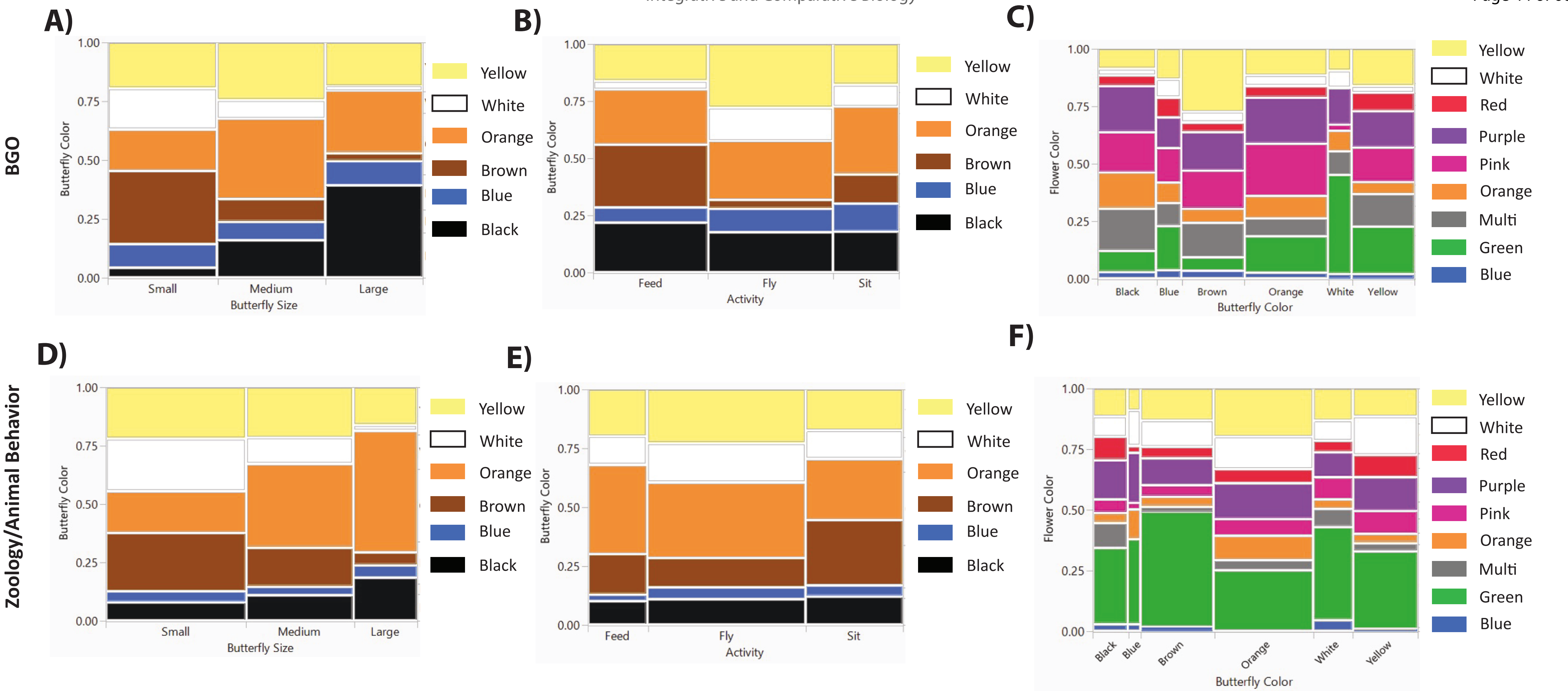
	Full year			**April, September, and October**		
Dependent variable	χ^2	p-value	N	χ^2	p-value	N
Butterfly size	**98.72**	**<0.0001**	**3,224**	8.5335	0.0739	2,234
Butterfly color	**130.49**	**<0.0001**	**3,208**	**49.52**	**<0.0001**	**2,210**
Butterfly activity	**153.61**	**<0.0001**	**3,225**	7.073	0.1321	2,245

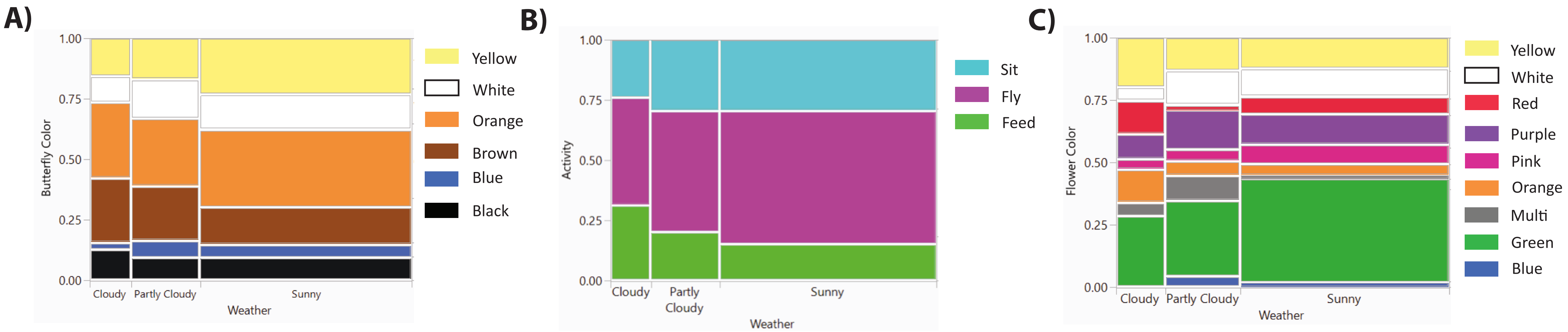
Table 3: Results of Chi-squared tests for BGO and University of Arkansas Students. Test results in bold are statistically significant after Bonferroni correction.

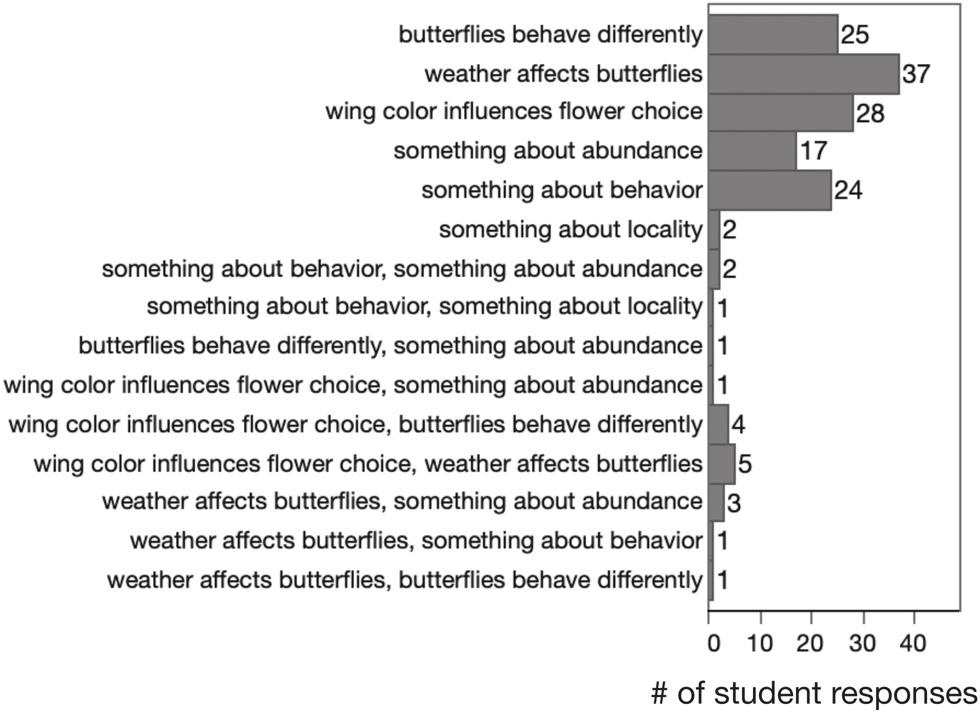
	BGO				UARK			
Test	χ^2	p-value	DF	N	χ^2	p-value	DF	N
Activity by butterfly color	**265.040**	**<0.0001**	**10**	**1971**	**64.172**	**<0.0001**	**10**	**1758**
Flower color by butterfly color	**179.103**	**<0.0001**	**40**	**1276**	**80.936**	**0.0001**	**40**	**879**
Butterfly color by size	**556.917**	**<0.0001**	**10**	**2006**	**277.126**	**<0.0001**	**10**	**1753**
Activity by size	**31.192**	**<0.0001**	**4**	**1970**	14.526	0.0058	4	1779
Flower color by size	**93.829**	**<0.0001**	**16**	**1271**	33.343	0.0067	4	891
Butterfly color by weather	NA	NA	NA	NA	26.221	0.0035	10	1240
Activity by weather	NA	NA	NA	NA	**23.429**	**0.0001**	**4**	**1281**
Size by weather	NA	NA	NA	NA	4.464	0.347	4	1249
Flower color by weather	NA	NA	NA	NA	**58.396**	**<0.0001**	**16**	**614**
Butterfly color by time of day	**77.760**	**<0.0001**	**10**	**1764**	**37.524**	**<0.0001**	**10**	**1569**
Activity by time of day	**52.577**	**<0.0001**	**4**	**1719**	5.470	0.242	4	1617
Size by time of day	12.841	0.0121	4	1749	4.821	0.306	4	1585


A)
Butterfly Observation Points
Northwest Arkansas
Class Sample Point
Indiviual Sample Point
Rivers
County Boundary
Contour: 100 m
Elevation (m)
200
300
400
500
600
700
0
7.5
15 km
N
BGO
Wilson Park
B)
Nebraska
Iowa
Illinois
Indiana
Ohio
Pennsylvania
Maryland
Colorado
Kansas
Missouri
West Virginia
Kentucky
Virginia
Oklahoma
Tennessee
North Carolina
New Mexico
Arkansas
South Carolina
Mississippi
Alabama
Georgia
Texas
Louisiana
Florida
Butterfly Observations
United States
Butterfly Observations
River
Ocean/ Lake
State Boundary
National Boundary
N
0
250
500 km


Full Data Set
April, September, October
A)
B)
Size
1.00
0.75
0.50
0.25
0.00
Small
Medium
Large
Adult
Child
Student
Age Group
C)
D)
Butterfly Color
Yellow
White
Orange
Brown
Blue
Black
E)
F)
Activity
Sit
Fly
Feed


A)
B)
C)
BGO
Butterfly Color
Butterfly Size
Small
Medium
Large
Activity
Feed
Fly
Sit
Flower Color
Butterfly Color
Black
Blue
Brown
Orange
White
Yellow
Yellow
White
Orange
Brown
Blue
Black
Red
Purple
Pink
Multi
Green
1.00
0.75
0.50
0.25
0.00
D)
E)
F)
Zoology/Animal Behavior


A)
1.00
0.75
0.50
0.25
0.00
Butterfly Color
Cloudy
Partly Cloudy
Sunny
Weather
Yellow
White
Orange
Brown
Blue
Black
B)
1.00
0.75
0.50
0.25
0.00
Activity
Cloudy
Partly Cloudy
Sunny
Weather
Sit
Fly
Feed
C)
1.00
0.75
0.50
0.25
0.00
Flower Color
Cloudy
Partly Cloudy
Sunny
Weather
Yellow
White
Red
Purple
Pink
Orange
Multi
Green
Blue


butterflies behave differently
25
weather affects butterflies
37
wing color influences flower choice
28
something about abundance
17
something about behavior
24
something about locality
2
something about behavior, something about abundance
2
something about behavior, something about locality
1
butterflies behave differently, something about abundance
1
wing color influences flower choice, something about abundance
1
wing color influences flower choice, butterflies behave differently
4
wing color influences flower choice, weather affects butterflies
5
weather affects butterflies, something about abundance
3
weather affects butterflies, something about behavior
1
weather affects butterflies, butterflies behave differently
1
0
10
20
30
40
# of student responses

Supplemental Material

Supplemental Methods for maps: All maps were produced in QGIS 3.6. We downloaded Arkansas state elevation data with a 5m latitudinal/ longitudinal resolution as a GeoTIFF file from the Arkansas GIS office at https://gis.arkansas.gov/product/2006-five-meter-resolution-digital-elevation-model-raster-new/. Arkansas county boundaries were downloaded as a polygon shapefile layer from https://gis.arkansas.gov/product/county-boundary-polygon/. Arkansas river data were downloaded as a shapefile layer from https://gis.arkansas.gov/product/adeq-water-base-layer/. United States state boundaries were downloaded as a polygon vector shapefile from the US Census Bureau at https://www2.census.gov/geo/pvs/tiger2010st/tl_2010_us_state10.zip. A polygon shapefile outlining the North American and Caribbean landmasses was downloaded from NaturalEarth Data at https://www.naturalearthdata.com/http//www.naturalearthdata.com/download/50m/physical/ne_50m_land.zip. Similarly, river and lake centerlines were downloaded from NaturalEarth Data at https://www.naturalearthdata.com/http//www.naturalearthdata.com/download/50m/physical/ne_50m_rivers_lake_centerlines.zip. Ocean boundaries were downloaded as a polygon shapefile from NaturalEarth Data at https://www.naturalearthdata.com/http//www.naturalearthdata.com/download/50m/physical/ne_50m_ocean.zip. Finally, the outlines of the countries of North America were downloaded from GADM.org. We imported the class and BGO observation data, formatted these data, and placed this layer on top of the other layers for both maps.

Supplemental Table 1: Survey participant demographic information by participant group. We had approximately 1,080-1,480 participants. For those who provided gender information, 352 selected "Female", 123 selected "Male", and one selected "Other". Fifty-three survey sheets from the BGO were filled out by a mix of genders.

	BGO	**Principles of Zoology**	**Animal Behavior**
Individual participants	346	242	16
School groups	40 large groups of 10-20 students each	NA	74 people in 6 groups
Age (from those who provided age)	175 Children (4-17) 88 adults (18+)	All 18-37	All 18-37

Supplemental Table 2: Nominal logistic model with the variables weather, time, and an interaction term of weather and time on butterfly activity.

Weather and Time on Activity				
Variable	P-Value	Chi-Square	DF	Observations
Weather	0.0479	9.58988252	4	1154
Time	0.4364	3.78121107	4	1154
Weather*Time	0.1059	13.1777678	8	1154

Supplemental Table 3: Nominal logistic model with the variables weather, time, and an interaction term of weather and time on butterfly color.

Weather and Time on Butterfly Color				
Variable	P-Value	Chi-Square	DF	Observations
Weather	0.0189	21.3303795	10	1113
Time	0.0299	19.9277236	10	1113
Weather*Time	0.0063	39.1968405	20	1113

Supplemental Table 4: Nominal logistic model with the variables weather, time, and an interaction term of weather and time on butterfly size.

Weather and Time on Size				
Variable	P-Value	Chi-Square	DF	Observations
Weather	0.4891	3.42682786	4	1122
Time	0.4968	3.37704516	4	1122
Weather*Time	0.3378	9.05337795	8	1122

Supplemental Figure 1: Botanical Garden of the Ozarks Survey Instructions

Butterfly Research:

A Citizen Science Project between Botanical Gardens of the Ozarks, University of Arkansas, and YOU!

Butterflies, birds, flowers, and a wide range of animals and plants come in a spectacular range of colors and shapes. One of the main goals of biology is understanding why this variation exists, and how changes in color and shape influence behavior, such as feeding, resting, and predator avoidance.

The Botanical Gardens of the Ozarks has teamed up with Dr. Erica Westerman, a professor at the University of Arkansas, Fayetteville, and the NWA community to study whether butterfly wing pattern (color, and size) can be used to predict butterfly behavior; particularly what flowers they visit, what time of day they are active, and what weather conditions they fly in. Dr. Westerman has deployed temperature and light sensors around the gardens, and we have compiled a check list of butterfly wing patterns and behaviors.

Your task, if you choose to accept it, is to keep your eyes out for butterflies as you travel the garden today. Every time you see a butterfly, check its color and size and what it's doing (feeding, flying, sitting). If it's feeding or sitting, please also note the color of the flower it is feeding or sitting on. If you happen to know the species of butterfly, go ahead and write that down too. And have fun!

At the end of your visit, please turn this sheet into the volunteer desk. The data you collect today will be compiled with that collected by many other Garden visitors and UARK researchers, and used to address questions concerning animal diversity and NWA pollinator community health.

Color Key= the color of most of the butterfly or flower… WH=white, YW=yellow, OG=Orange RD=red, BL=blue, BK=black, BR=brown, PL=purple, GR=green, PK=pink

SM=small (pencil eraser to watch face, or slightly bigger) M= medium (about the size of a key) LG= large (bigger than a key)

Date: **Time:** **Your age:**
Gender: F M O

Butterfly	**Color**	**Size**	**Activity**	**Flower/plant color**
1	WH YW O RD BL BK BR	SM M LG	Feed Fly Sit	WH YW O RD BL GR PL PK
2	WH YW O RD BL BK BR	SM M LG	Feed Fly Sit	WH YW O RD BL GR PL PK
3	WH YW O RD BL BK BR	SM M LG	Feed Fly Sit	WH YW O RD BL GR PL PK
4	WH YW O RD BL BK BR	SM M LG	Feed Fly Sit	WH YW O RD BL GR PL PK

*Data sheet goes up to 23 butterflies. The half sheet goes to 6 butterflies.

Supplemental Figure 2: Zoology Butterfly Survey Instructions.

Butterfly Phenology & Behavior:

University of Arkansas, Botanical Gardens of the Ozarks, and YOU!

Butterflies, birds, flowers, and a wide range of animals and plants come in a spectacular range of colors and shapes. One of the main goals of biology is understanding why this variation exists, and how changes in color and shape influence behavior, such as feeding, resting, and predator avoidance.

Dr. Erica Westerman has teamed up with the Botanical Gardens of the Ozarks, Principles of Zoology, Animal Behavior, and the NWA community to study whether butterfly wing pattern (color, and size) can be used to predict butterfly behavior; particularly what flowers they visit, what time of day they are active, and what weather conditions they fly in.

UA Principles of Zoology students play a special role in this project, as you are collecting data which we can use as a comparison to that from the Botanical Gardens. In addition, you are collecting a large amount of data for a specific 11-day period. This collection will happen every year, and will be correlated with weather patterns observed in Northwestern Arkansas to see if, and how, the butterfly community changes in response to variation in weather patterns. On your 30-minute walk, keep your eyes out for butterflies. Every time you see a butterfly, check its color and size and what it's doing (feeding, flying, sitting). If it's feeding or sitting, please also note the color of the flower it is feeding or sitting on. If you happen to know the species of butterfly, go ahead and write that down too. And have fun!

Please turn in your data sheet by the end of class Tuesday, Oct 6th. The data you collect today will be compiled with that collected by many other students and UARK researchers, and used to address questions concerning animal diversity and NWA pollinator community health.

Color Key= the color of most of the butterfly or flower… WH=white, YW=yellow, O=Orange, RD=red, BL=blue, BK=black, BR=brown, PL=purple, GR=green, PK=pink

SM=small (pencil eraser to watch face, or slightly bigger) M= medium (about the size of a key) LG= large (bigger than a key)

Latitude: **Longitude**: **Weather**: (sunny /partly cloudy /cloudy /rainy)

Date: **Time:** **Your age:** **Gender: F M O**

Butterfly	**Color**	**Size**	**Activity**	**Flower/plant color**
1	WH YW O RD BL BK BR	SM M LG	Feed Fly Sit	WH YW O RD BL GR PL PK
2	WH YW O RD BL BK BR	SM M LG	Feed Fly Sit	WH YW O RD BL GR PL PK
3	WH YW O RD BL BK BR	SM M LG	Feed Fly Sit	WH YW O RD BL GR PL PK
4	WH YW O RD BL BK BR	SM M LG	Feed Fly Sit	WH YW O RD BL GR PL PK

*Data sheet goes up to 23 butterflies.

Supplemental Figure 3: Animal Behavior Survey Instructions 2017-2019

Butterfly Research:

A Citizen Science Project between Botanical Gardens of the Ozarks, University of Arkansas, and YOU!

Butterflies, birds, flowers, and a wide range of animals and plants come in a spectacular range of colors and shapes. One of the main goals of biology is understanding why this variation exists, and how changes in color and shape influence behavior, such as feeding, resting, and predator avoidance.

The Botanical Gardens of the Ozarks has teamed up with Dr. Erica Westerman and the NWA community to study whether butterfly wing pattern (color, and size) can be used to predict butterfly behavior. Specifically, what flowers they visit, time of day they are active, and what weather conditions they fly in.

UA Animal Behavior students play a special role in this project, as you are collecting data for our second field site, which we can use as a comparison to the Botanical Gardens. Wilson Park has a diverse collection of plants, but is more urban, and less managed, than the gardens. Using your data, we will be able to determine whether butterflies exhibit similar behaviors in these two habitats. As you walk through the park today, keep your eyes out for butterflies. Every time you see a butterfly, check its color and size and what it's doing (feeding, flying, sitting). If it's feeding or sitting, please also note the color of the flower it is feeding or sitting on. If you happen to know the species of butterfly, go ahead and write that down too. And have fun!

At the end of your walk, please turn this sheet in to your TA (Matt). The data you collect today will be compiled with that collected by many other students and UARK researchers, and used to address questions concerning animal diversity and NWA pollinator community health.

Color Key= the color of most of the butterfly or flower… WH=white, YW=yellow, O=Orange RD=red, BL=blue, BK=black, BR=brown, PL=purple, GR=green, PK=pink (please categorize grey as white)

SM=small (pencil eraser to watch face, or slightly bigger) M= medium (about the size of a key) LG= large (bigger than a key)

Date: **Time:** **Your age:**
Gender: F M O

Weather: Sunny Cloudy Partially-Cloudy Rainy Approx Temperature: Warm Cold

Butterfly	**Color**	**Size**	**Activity**	**Flower/plant color**
1	WH YW O RD BL BK BR	SM M LG	Feed Fly Sit	WH YW O RD BL GR PL PK
2	WH YW O RD BL BK BR	SM M LG	Feed Fly Sit	WH YW O RD BL GR PL PK
3	WH YW O RD BL BK BR	SM M LG	Feed Fly Sit	WH YW O RD BL GR PL PK

*Data sheet goes up to 23 butterflies.

Supplemental Figure 4: Animal Behavior Survey Instructions 2020

Butterfly Phenology & Behavior:
University of Arkansas, Botanical Gardens of the Ozarks, and YOU!

Butterflies, birds, flowers, and a wide range of animals and plants come in a spectacular range of colors and shapes. One of the main goals of biology is understanding why this variation exists, and how changes in color and shape influence behavior, such as feeding, resting, and predator avoidance.

Dr. Erica Westerman has teamed up with the Botanical Gardens of the Ozarks, Principles of Zoology, Animal Behavior, and the NWA community to study whether butterfly wing pattern (color, and size) can be used to predict butterfly behavior; particularly what flowers they visit, what time of day they are active, and what weather conditions they fly in.

UA Animal Behavior students play a special role in this project, as you are collecting data which we can use as a comparison to that from the Botanical Gardens. In addition, you are collecting a large amount of data for a specific 2-day period. This collection will happen every year, and will be correlated with weather patterns observed in Northwestern Arkansas to see if, and how, the butterfly community changes in response to variation in weather patterns. On your 30-minute walk, keep your eyes out for butterflies. Every time you see a butterfly, check its color and size and what it's doing (feeding, flying, sitting). If it's feeding or sitting, please also note the color of the flower it is feeding or sitting on. If you happen to know the species of butterfly, go ahead and write that down too. And have fun!

Please turn in your data sheet and photo (landscape or butterfly) via e-mail by midnight Saturday, April 11th. The data you collect will be compiled with that collected by many other students and researchers, and used to address questions concerning animal diversity and NWA pollinator community health.

Color Key= the color of most of the butterfly or flower… WH=white, YW=yellow, O=Orange, RD=red, BL=blue, BK=black, BR=brown, PL=purple, GR=green, PK=pink (please categorize grey as white)

SM=small (pencil eraser to watch face, or slightly bigger) M= medium (about the size of a key) LG= large (bigger than a key)

Latitude: **Longitude**: **Weather**:

Date: **Time:** **Your age:**
Gender: F M O

Butterfly	**Color**	**Size**	**Activity**	**Flower/plant color**
1	WH YW O RD BL BK BR	SM M LG	Feed Fly Sit	WH YW O RD BL GR PL PK
2	WH YW O RD BL BK BR	SM M LG	Feed Fly Sit	WH YW O RD BL GR PL PK
3	WH YW O RD BL BK BR	SM M LG	Feed Fly Sit	WH YW O RD BL GR PL PK
4	WH YW O RD BL BK BR	SM M LG	Feed Fly Sit	WH YW O RD BL GR PL PK

*Data sheet goes up to 23 butterflies.

Supplemental Results

Butterfly Numbers

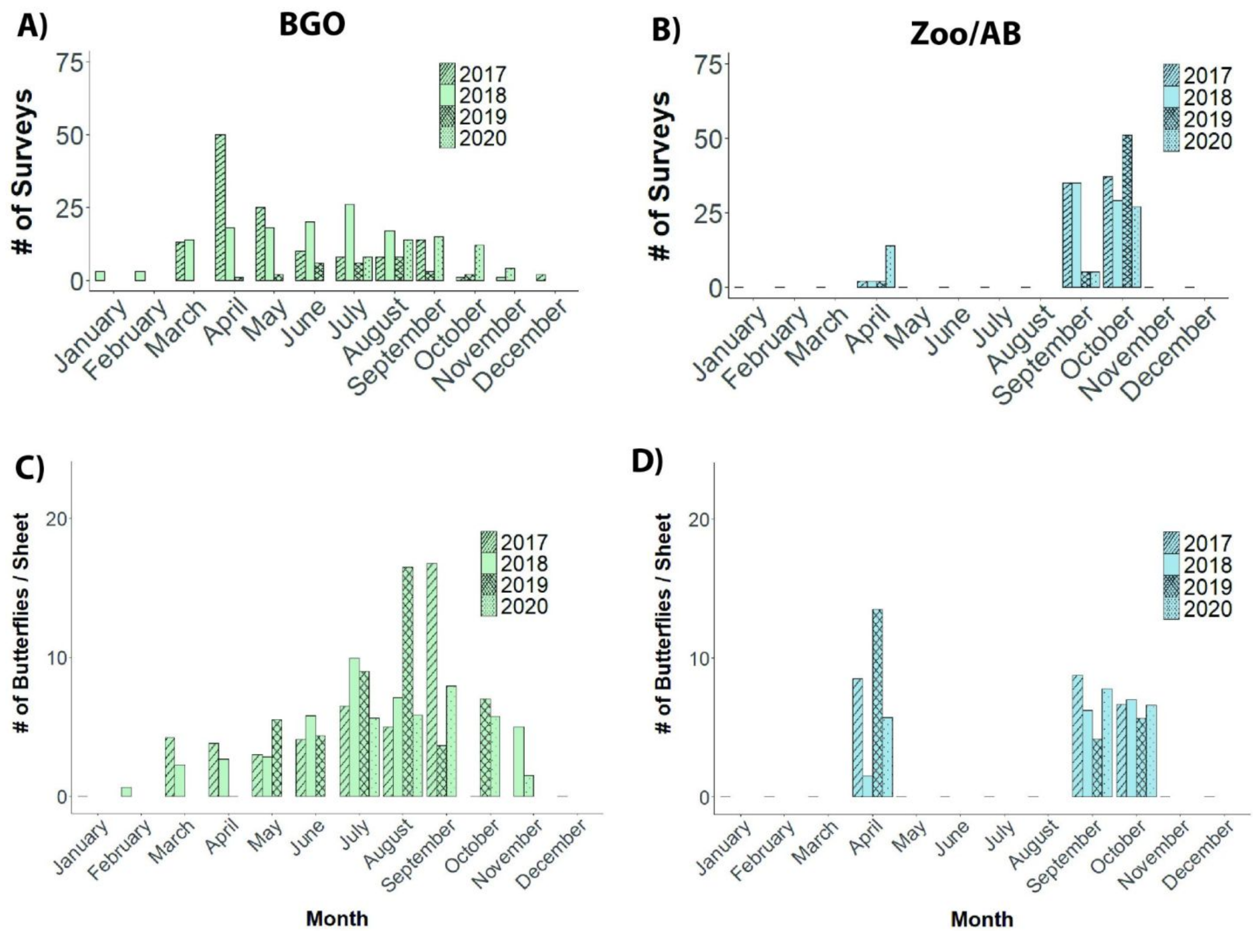
When averaging observations by survey sheet for all years, the highest monthly average of butterflies observed per survey sheet was 8.5 butterflies in July and September (Supplemental Figure 5). In a single year, the highest monthly average of butterflies observed per survey sheet was 16.5 butterflies for August 2019. The highest number of butterflies counted in a month was 541 in September 2017, but when pooling all years together the highest number of butterflies counted in a month were 1,003 for October. This is likely a result of Zoology students sampling during the last week of September and first week of October each year.

1,512 butterflies observed were small, 1,324 were medium, and 993 butterflies were large. 1,079 butterflies were orange, 798 were yellow, 625 were brown, 599 were black, 445 were white, and 277 were blue.

Effect of year on butterfly color, behavior, and size

Survey year had an effect on the observed color of butterflies in data collected by BGO participants ($\chi 2$=149.365, P<0.0001, n=2,064) and University of Arkansas students ($\chi 2$=98.029, P<0.0001, n=1,760). For BGO participants, survey year also had an effect on butterfly behavior ($\chi 2$=208.447, P<0.0001, n=2,012) and butterfly size ($\chi 2$=54.442, P<0.0001, n=2,048) (Supplemental Figure 6). For University of Arkansas students, survey year did not have an effect on butterfly behavior ($\chi 2$=16.417, P=0.01137, n=1,814) or butterfly size ($\chi 2$=12.635, P=0.0492, n=1,781) (Supplemental Figure 6).

Supplemental Figure 5: A) Number of surveys conducted each year at the BGO. B) Number of surveys conducted each year in University of Arkansas college courses (Zoology and Animal Behavior). C) Number of butterflies/sheet observed each year at BGO. D) Number of butterflies/sheet observed each year by college courses.



Supplemental Figure 6: **Butterfly color, behavior, and size distribution varied over time**. A-C BGO: A) Mosaic plot of proportion of butterflies of each color by year. B) Mosaic plot of proportion of butterflies exhibiting each behavior by year. C) Mosaic plot of proportion of butterflies of each size by year. D-F University of Arkansas: D) Mosaic plot of proportion of butterflies of each color by year. E) Mosaic plot of proportion of butterflies exhibiting each behavior by year. F) Mosaic plot of proportion of butterflies of each size by year.