Butterfly Community Monitoring on City of Boulder Open Space and Mountain Parks Property: Analysis of the Changes in Species Richness and Diversity from 2002 to 2016

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Front Cover: View of the Flatirons looking northwest along transect 9, Doudy Draw, from point T9E on Lindsey – West (north), a City of Boulder Open Space and Mountain Parks property, Boulder County, CO. June, 2016.

EXECUTIVE SUMMARY

Butterfly Community Monitoring on City of Boulder Open Space and Mountain Parks Property: Analysis of the Changes in Species Richness and Diversity from 2002 to 2016. John Sovell, Colorado Natural Heritage Program; johnsovell@colostate.edu, (970) 491-6052. January 2017.

The City of Boulder Open Space and Mountain Parks department (OSMP) manages properties that by virtue of their location at the interface between the prairies and mountains include a diverse number of plant communities, which support high butterfly biodiversity. Over the past 15 years, OSMP has sampled the butterfly community in five different years, at 18 transects of 400 m length, distributed in five different habitat types (Foothills Grassland, Foothills Riparian, Grassland, Montane Woodland, Prairie Riparian, and Tallgrass). Data was analyzed using a mixed anova with habitat analyzed as a fixed effect and year as a random effect. The response variables included species richness and Shannon's and Simpson's indices of diversity. The goal of this document is to determine how butterfly communities have changed over time, with reference to habitat type, time, and their interaction.

There are distinct differences in the richness and diversity of the butterfly community among the habitat types sampled and also over time with earlier years of the study having greater values for both species richness and diversity. Among years, there were significantly more species detected in the first three sample years of 2002, 2007, and 2008 compared to the later years of 2015 and 2016. Shannon's diversity index *H* varied significantly by habitat and declined significantly over time, but the habitat by year interaction was not significant. Simpson's diversity index *D* varied significantly only by habitat and not over time, while the habitat by year interaction was not

significant. The Forest Riparian habitat type harbored more butterfly species than other habitats, while the Prairie Riparian habitat type exhibited lower values of diversity.

There are multiple potential explanations for the patterns in species richness and diversity observed among the years and habitats studied. The patterns could be attributed to the enhanced native character of the less disturbed plant community at higher elevations within the study area compared to the low elevation habitats, where more intense historical and recent grazing has modified the plant community. The increased diversity of the herbaceous plant community within moist riparian areas compared to the surrounding dry uplands throughout the study area are also probably contributing to the observed patterns. Both butterfly habitat quantity and its quality may be decreasing as the Boulder region urbanizes. Urbanization and its consequent impacts including habitat loss and fragmentation, agriculture, and the introduction of invasive nonnative plants may be contributing to changes in the condition and extent of native plant associations within the study area.

It is important to emphasize that butterflies form metapopulations, where local and somewhat isolated populations are connected to each other through dispersal (Spaulding 2005). Consequently, maintaining habitat continuity at the landscape scale is critical if connectivity between metapopulations, and ultimately conservation of butterfly populations, are to be realized (New et al. 1995).

Important management considerations include:

- Increasing the size of protected areas in order to support butterfly metapopulation dynamics.

- Controlling nonnative plant species to improve habitat quality, native plant diversity, and vegetation heterogeneity is critical to maintaining the integrity of the habitat upon which butterflies depend.
- Collaboration with other governmental and nongovernmental units to create and maintain an independent yet complimentary system of widespread nature reserves that can successfully conserve butterfly biodiversity (Shuey 2005) is important.
- Controlled burning can assist in the establishment and maintenance of native warm-season grasses
- Cattle grazing should be designed to protect and enhance areas containing nectar and pollen resources.
- Restoration should focus on using seed mixes that maximize native plant diversity with seed sourced from local populations, when available, to assure genetic compatibility.
- Riparian management should include fencing habitat to either completely or partially defer grazing by livestock while offering alternate watering sites.
- Recreation can result in habitat fragmentation and needs consideration from natural resource managers of open space lands, where protection of native butterflies is part of the management goals.
- Haying should be restricted to fall through early spring to maximize availability of flowering plants for native butterflies.

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ABSTRACT

Butterfly populations are naturally patchy and undergo extinctions and recolonizations. Recent published research indicates that butterfly fauna show a net loss over time in species richness and diversity, when populations are subject to anthropogenic disturbances like development, climate change, and invasion by nonnative plant species. This document reports on an analysis of changes in butterfly community over time at 18 transects, distributed in six habitat types, and sampled in five different years: 2002, 2007, 2008, 2015, and 2016. Species richness and diversity was greatest in earlier years of the study and all habitats studied exhibited declining trends in both richness and Shannon's diversity index H over time (richness, $m = -0.8$; Shannon diversity, $m = -0.07$). There were also differences in diversity among the habitats sampled with the Forest Riparian habitat type supporting more butterfly species, while the Prairie Riparian habitat type had lower diversity. This analysis represents a snapshot of the butterfly community among time periods, rather than a comprehensive survey making it difficult to identify the causes for the observed patterns. Some factors that could explain the patterns observed among habitats include the greater quality of the native plant community at higher elevations, a greater diversity of plants in riparian areas compared to adjacent uplands, exurban development, more intensive historical and recent grazing of riparian habitats at lower elevation, the effects of recreation, variability in climate among years, and climate change. Conserving butterfly communities of the study area may require increasing the size of protected areas, improving the quality of their habitat, managing nonnative plants, and increasing native plant diversity. Additionally, understanding that regional butterfly diversity is dependent upon maintaining habitat continuity at the landscape scale between butterfly metapopulations is important.

Keywords: butterfly, diversity, species richness, urbanization, time, vegetation heterogeneity

INTRODUCTION

Decreases in the abundance, distribution and diversity of animal species in recent decades have been widely documented as species have responded to land-use pressures such as urban expansion, the alteration of habitat structure from the spread of nonnative plants and climate change (Hill et al. 1999, Wilson et al. 2007). Changes in species distribution and local abundance will bring about changes in biological assemblages at local scales (González-Megías et al. 2008). Because taxa with different characteristics respond in different ways to climate and land-use changes, the frequencies of different functional types within communities may be changing as well. For example, responses to environmental change are already known to depend on the life history traits (Cardillo et al. 2005, Perry et al. 2005), habitat characteristics (Warren et al. 2001, Menendez et al. 2006) and types of distribution (Jiguet et al. 2006) of the species concerned.

The City of Boulder Open Space and Mountain Parks (OSMP) has been surveying butterfly communities in 18 transects (400m linear transect, 5m each side of transect centerline) in five different years. Survey work was initiated in 2002, the study sampled three transects within each of six different habitats over three months, June through July (Armstead 2003). The habitats sampled and the number of visits per transect for each year sampled are listed in Table 1.

The goal of this document is to determine how butterfly communities have changed over time, with reference to habitat type, time, and their interaction.

The first survey in 2002, conducted during a period of below normal precipitation, documented 995 individual butterflies from 53 different species (Armstead 2003). The survey indicated that foothill riparian habitats were "diversity hot spots" for butterflies and that grassland habitats contained species of conservation concern that require high quality grasslands for their persistence (Armstead 2003). In 2007 and 2008, when sampling effort was doubled (see Table 1), there were an average of 3600 butterflies per year recorded at the 18 survey transects, representing a total of 49 species (Robinson et al. 2012). These surveys indicated that Prairie Riparian and Foothills Riparian sites were highly suitable for butterflies in this ecosystem, regardless of weather conditions (Robinson et al. 2012). In 2015, there were 673 individual butterflies representing 25 different species documented at the 18 survey transects (Sovell 2016). The 2015 survey indicated that butterfly species richness and abundance has declined at the 18 OSMP survey transects (Sovell 2016). The impression that butterflies are declining from numbers documented in the 2000s was also support in 2016, when 613 individual butterflies representing 29 different species were documented at the 18 survey transects.

METHODS

Study Area

The study area is located in north-central, Colorado (39^{0}59'39.47W-105^{0}14'1.257"W) (Figure 1). It is an area consisting of Rocky Mountain foothills on the west, grading into prairie grassland to the east and extends over 26,900 ha with altitudes ranging from 1,960 to 1,545 m. The climate is semi-arid with a mean annual rainfall of 525 mm and 2,260 mm of snowfall. Mean annual temperature is 10.9^{0}C with lowest values in December and the highest in July. The 18 survey transects are located on OSMP property that is managed to provide recreational opportunities and conserve wildlife habitat.

The transects consist of a mosaic of plant communities (Armstead 2003, Robinson et al 2012) including:

- foothills grassland with various species including cheatgrass (*Bromus tectorum*), western wheatgrass (*Pascopyrum smithii*), and prairie Junegrass (*Koeleria macrantha*);
- foothills riparian canyon corridors with an overstory of trees such as narrow-leaved willow (*Salix exigua*) and a thick brush understory of choke cherry (*Prunus virginiana*) and some perennial vines like riverbank grape (*Vitis riparia*);
- grassland containing mixed and shortgrass prairie species;
- montane woodland dominated by ponderosa pine (*Pinus ponderosa*) and containing various grasses including big bluestem (*Andropogon gerardii*), orchard grass (*Dactylis glomerata*), and smooth brome (*Bromus inermis*) and dwarf shrubs;
- prairie riparian corridors with an overstory of cottonwood (*Populus deltoides*), a shrub sub-canopy of narrow-leaf willow (*Salix exigua*) and choke cherry (*Prunus virginiana*), and a groundcover of grasses and perennial forbs; and
- tallgrass prairie containing big bluestem (*Andropogon gerardii*) and Indiangrass (*Sorghastrum nutans*) along with other tallgrass remnants.

Butterfly Sampling

To test for changes in the butterfly community, butterfly surveys in 2015 and 2016 followed the same methodology used from 2002 through 2008 (Armstead 2003, Robinson et al. 2012). This involved surveying transects of 400m standard length at 3 locations per habitat type (6 habitats in total), with transects located in the same habitat type and among habitats placed ≥ 300m apart (Figure 1). In 2002, 2015, and 2016 each transect was surveyed three times, once per month from June through August. In 2007 and 2008, each transect was surveyed six times, twice per month from June through August. Because of this difference in sampling effort, only data for the first sample from each month in 2007 and 2008 was analyzed. The habitats surveyed were representative of the predominant plant community associations along the foothills of the Colorado Front Range.

Surveys were conducted only during optimal butterfly flight conditions, when the following criteria were met: between 09:00 and 15:00 hours, less than 30% cloud cover, less than 24 kph winds, and temperatures between 24 and 38 °C (Van Swaay et al. 2015, Woods et al. 2008). Butterflies were surveyed by recording the presence of each individual within 5 m to either side of the observer, who walked transects at a slow, even pace. Average survey duration was about 45 minutes. Individuals of easily recognized species were identified by sight, whereas less recognizable species were netted and either identified on site or photographed and identified at a later date.

Statistics

The data was analyzed as a mixed design with habitat type analyzed as a fixed effect and year as a random effect. A complicating factor is that measures were repeated over time creating a need to distinguish among-transect variables (i.e., habitat) from within-subject variables (i.e., year). Specifically:

- Subjects are transects (n = 18),
- The among-subject variable is the six habitat types (i.e., each transect can only have one value for habitat), and
- The within-subject variable is the five sampled years (i.e., year can vary within each transect).

- Response variables analyzed include native species richness and Shannon's and Simpson's indices of diversity.

Species richness was calculated as the number of native species recorded on transect during the monthly sampling event. The number of native species recorded for the months of June, July, and August were summed and divided by three, the number of months sampled. For the years 2007 and 2008, when samples were conducted twice per month, only the first sample of the month was used to calculate native species richness.

Shannon's diversity index *H* accounts for both abundance and evenness of the species present and its calculation can be found in Table 2. In ecological studies, typical values range from 1.5 (low diversity) to 3.5 and the index is rarely greater than 5 (Krebs 2014). The Shannon index increases as both the richness and the evenness of the community increase. The Shannon index is best at identifying differences in diversity where rare and abundant species are both equally important in structuring the community (Morris et al. 2014).

Simpson's index of diversity *D* is often used in complement with Shannon's H. Simpson suggested that diversity was related to the probability that two individuals picked at random belong to the same species. (Krebs 2014). To convert this probability to a measure of diversity, the complement of Simpson's original measure, 1-D, is used (probability that two randomly drawn individuals belong to different species). For finite populations, the appropriate estimator differs from Simpson's original equation (Table 2) (Krebs 2014). Simpson's index (1 - D) ranges from 0 (low diversity) to 1 and provides an intuitive proportional measure of diversity that is much less sensitive to species richness (Magurran 2004).

The Anova model in R is **Response = year*habitat +(transect/(year))**.

Tukey's multiple comparison of means test was performed on all pairs of means post hoc to determine whether there were significant differences at the 0.10 probability level for any main effect or interaction term that was significant. The Tukey test uses intervals based on the range of sample means rather than the individual differences of each pair of compared means. The intervals returned are based on the studentized range distribution that takes into account the number of means being compared and controls for the Type I error rate across multiple comparisons (R Core Team 2016).

RESULTS

Species Richness

The mean values for species richness showed a declining trend over time (Figure 2). Butterfly species richness varied significantly by habitat, declined significantly over time, and there was a habitat type by year interaction (Table 3).

Contrasts revealed that Forest Riparian transects had consistently greater species richness than did transects in the other five habitat types (Table 4). Also, significantly fewer species were detected in 2015 and 2016 than were detected in the earlier three sample years of 2002, 2007, and 2008 (Table 5).

Species Diversity

The mean values of Shannon's *H* showed a declining trend over time, regardless of habitat (Figure 3). Alternatively, the values of Simpson's diversity index showed a decline over time in some habitats (Montane Woodland, Prairie Riparian, and Tallgrass) and an increasing or relatively stable trend in others (Foothills Grassland, Forest Riparian, and Grassland) (Figure 4).

Shannon's *H* varied significantly by habitat and declined significantly over time, but the habitat by year interaction was not significant (Table 6). Simpson's *D* varied significantly by habitat, but not over time, and the habitat by year interaction was not significant (Table 9).

Contrasts revealed that the value of Shannon's *H* was significantly less for the Prairie Riparian transects than for transects at four (Forest Grassland, Forest Riparian, Mountain Woodland, and Tallgrass) of the other five habitat types (Table 7). In 2007, the values of Shannon's *H* among habitat types was significantly greater than in the two most recent years sampled (2015 and 2016) (Table 8).

Simpson's D varied significantly by habitat type (Table 9). Contrasts revealed that Simpson's *D* was significantly less at the Prairie Riparian transects than for the same four habitat types identified by Shannon's *H* (Forest Grassland, Forest Riparian, Mountain Woodland, and Tallgrass) (Table 10). The values of Simpson's *D* did not vary over time (Table 11). The species count varied considerably by year with lower values recorded for 2015 and 2016. Simpson's *D* is less sensitive to species richness, while Shannon's *H* increases as richness increases. This might have been why Simpson's index did not record a significant difference in diversity over time, while Shannon's *H* did.

DISCUSSION

There are distinct differences in the richness and diversity of the butterfly community among the habitat types, with forest riparian habitats having more species than other habitats and prairie riparian habitats having lower diversity. There was also differences over time, with earlier years of the study having greater values for both species richness and for Shannon's diversity index H.

The elevated species richness in Forest Riparian transects probably results from a combination of the enhanced native composition of the plant community at higher elevation riparian zones compared to riparian zones at lower elevation (pers. obs.). Riparian areas have unique rich fertile soils, higher soil moisture levels than surrounding uplands, and high water tables, which contributes to a diverse community of plants (Gregory et al. 1991, Brosofske et al. 1997, Lyon and Sagers 1998, Ilhardt et al. 2000, Naiman et al. 2000). These factors increase the availability of both native host plants and the abundance of herbaceous nectar sources within riparian forest habitats, which has positive effects on the butterfly community in these habitats (Nelson and Anderson 1994, McKinney 2008, Hanuly and Horn 2011).

Among years, significantly more species were detected in the first three sample years of 2002, 2007, and 2008 compared to the later years of 2015 and 2016. Due to the gap in years among surveys that were conducted from 2002 to 2016, this analysis represents a snapshot of the butterfly community among time periods, rather than a comprehensive survey. Consequently, identifying the causes for the decline in richness noted in 2015 and 2016 is difficult. There may be multiple reasons for the observed decline. Both butterfly habitat and its quality may be decreasing as the Boulder region urbanizes (Collinge et al. 2003). The spread of invasive nonnative plants, agriculture, variations in weather among sample years, and climate change may also be contributing to changes in the condition and extent of native plant associations within the study area. All of these factors could be operating in tandem or individually to affect butterfly species richness.

Research on exurban development conducted northeast of Fort Collins, Colorado found that disturbances caused by the construction of houses, roads, trails, or grazing by livestock results in the increased prevalence of non-native plants and decreased native plant diversity (Maestas et al

2003). Maestas (2003) and his colleagues conducted their research 50 miles due north of the OSMP study area at a site that was further from the Fort Collins urban center and less impacted by exurbanization than are the OSMP transects (pers. obs.), still, the effect of disturbance was significant. Roads and trails, in particular, are well recognized as corridors for the spread of nonnative flora (Jordan 2000, Hansen et al. 2005). Additionally, research has shown that public lands have less native plant diversity and a greater prevalence of non-native plants than do ranches or public land without recreation, probably due to increased human traffic in public areas with public recreation (e. g. horse riding, hiking, biking) acting as conduits for invasive plants (Larsen et al. 2001, Maestas et al. 2003, Decker 2012).

The location of agricultural activities (haying, grazing, cropping) is often nonrandom and tends to be concentrated at lower elevations and often near water resources. It appears that all three Prairie Riparian transects experienced some level of past grazing or are adjacent to irrigated hay fields. The more intense agriculture use of the prairie riparian landscape appears to have degraded the plant community and, in turn, the butterfly community of this habitat type beyond that of the other habitats sampled within the study area (pers. obs.).

Agricultural activities, both historic and contemporary, are implicated in decreasing native plant diversity and increasing nonnative plant diversity (Decker et al. 2012). This coupled with the greater risk of riparian areas, relative to other habitats, to nonnative plant invasion (Larsen et al. 2001, Decker 2012) may increase non-native plant diversity at the prairie riparian transects. Nonnative plants are known to negatively impact butterfly communities. The greatest effect nonnative plants have on butterfly communities is their crowding out or shading of both native host plants and plants that serve as butterfly nectar sources, which ultimately results in a less diverse community of butterflies (Moron’ et al. 2009, Hanuly and Horn 2011). Research has also shown that grazing negatively affects butterfly communities through reductions in vegetation height and decreasing vegetation heterogeneity (Soderstrom et al 2001, Kruess and Tscharntke 2002, Moranz et al 2012).

Researchers have also identified strong associations between weather and population fluctuations in butterflies (Roy et al. 2001, WallisDe Vries 2011). The main negative associations were with drought and extreme heat (particularly during summer) causing declines in butterfly populations while average spring precipitation and temperatures had positive effects on population size (Piessens et al. 2009, Robinson et al. 2012, Sovell 2015). Additionally, changes in climate projected for the region including gradual increases in temperature and reductions in rainfall, combined with extreme weather events such as heat waves and prolonged drought (Melillo et al. 2014) are expected to negatively affect butterflies (Stefanescu et al. 2004, WallisDe Vries 2011, Oliver et al. 2015). Consequently, climate change and variability in weather patterns among the years surveyed could explain the decline overtime in butterfly species richness reported here.

The affects that exurban development, recreation, climate change, and historical and current agriculture have on butterfly community richness are probably additive and likely operate over extended time periods with their full impact being realized over decades. The effects associated with current and historical grazing and farming may still be operating within this system and may be enhanced by interactions with more recent and ongoing disturbances like exurban development, recreation, and climate change. Additional research would be required to identify what factors, and in what proportion, they are contributing to the decline in the butterfly species richness observed in 2015 and 2016.

The measures of both diversity indices also showed differences by habitat type and the values of Shannon's H also showed trends over time with 2015 and 2016 values significantly less than the values for 2002, 2007, and 2008. The trends in diversity by habitat type and year may also be attributable to the same mechanisms affecting species richness and the variation in richness by habitat type; exurban development, recreation, climate change, and historical and current agriculture. These disturbances may be affecting butterfly community diversity through their effects on native plant diversity and butterfly populations in ways similar to that discussed for butterfly species richness. Drought, extreme heat, the loss of persistent host plant and nectar sources, reductions in vegetation height, decreasing vegetation heterogeneity, and even excessive rainfall may all be interacting to negatively affect butterfly community diversity at the OSMP transects (Soderstrom et al 2001, Kruess and Tscharntke 2002, Moranz et al 2012).

It is important to realize that butterflies form metapopulations, where local and somewhat isolated populations are connected to each other through dispersal (Spalding 2005). Increasing or maintaining current connectivity between butterfly metapopulations, increasing the size of protected areas, and improving habitat quality by managing nonnative plants could stabilize and ultimately increase the regional diversity of butterflies within the study area (New et al. 1995). Other city, county, state, and federal protected lands within the area increases suitable habitat available to support butterflies. When considering all of these components of the protected landscape, there is enough protected habitat in the study area to support butterfly metapopulation dynamics. A system of independent yet complimentary nature reserves like those of this area have proven effective in conserving butterflies (Shuey 2005).

This report includes the findings of the data analysis and is accompanied by electronic versions of maps and any pertinent GPS locations.

Management Considerations

Research suggests that for temperate butterfly species, high quality larval habitat is the most important factor determining the size and persistence of butterfly populations (Thomas et al 2011). Consequently, increasing the acreage protected as open space, maintaining the quality of the protected lands, and restoring disturbed habitat within the study area will help conserve butterfly biodiversity and support the dynamics of butterfly metapopulations. This can, in part, be accomplished by collaborating with other governmental and nongovernmental units within the area to create and maintain an independent yet complimentary system of widespread nature reserves that can successfully conserve the butterfly community (Shuey 2005).

The following recommendations are based on goals identified for grassland, woodland, and riparian habitat management and expands upon discussions found in Kettler and Pineda (1999) and Sovell (2015 and 2016).

Fire

Controlled burning can assist in the establishment and maintenance of native warm-season grasses. However, prescribed burns should be conducted from fall into early spring, when butterflies are not active (Warriner and Hutchins 2016). Over-wintering stages (larvae and eggs) will still suffer some mortality from fall to spring burns so fire should only be applied to 30% or less of a site (Warriner and Hutchins 2016). Unburned areas will offer food resources and nest sites for insects, including butterflies, to recolonize burned sites as vegetation recovers. Allow sufficient time, 6 to 8 years (Swengel and Swengel 2007), between burns for thatch to accumulate and enable butterfly populations in burned sections to recover. Fires that are too frequent, widespread (over 30-40 acres in size), or intense (Romme et al. 2003) can reduce or eliminate native butterfly populations. Consequently, longer periods between burns, if compatible with other management goals, will allow the butterfly populations to persist on open space properties (Warriner and Hutchins 2016).

Grazing

Cattle grazing should be designed to protect and enhance areas containing nectar and pollen resources (Warriner and Hutchins 2016). Grazing, when combined with herbicides and biocontrol agents, can help control invasive plants (Tu et al. 2001). Low intensity, short duration grazing from fall into early spring will have the least impacts on native insect resources (Warriner and Hutchins 2016), including host plant and nectar resources for butterflies. Cool season grazing will also help control cool-season, non-native grasses including cheatgrass, Canada bluegrass, and smooth brome (Kettler and Pineda 1999, Tu et al. 2001). Grazing when butterfly larvae are active on host plants (late spring to early fall) can result in larval mortality, and if species of concern are present, grazing should be avoided during their life cycle (Warriner and Hutchins 2016). Grazing should only be applied to 30% or less of a site in a given year (Warriner and Hutchins 2016). High intensity, short duration grazing may be needed in restoration efforts to increase seed germination or control non-native grasses (Warriner and Hutchins 2016). Avoid grazing with goats or sheep as these feed more heavily on important nectar and pollen-bearing wildflowers (Warriner and Hutchins 2016).

Habitat Restoration

Restoration should focus on using seed mixes that maximize native plant diversity with seed sourced from local populations, when available, to assure genetic compatibility. A succession of native flowers should be available throughout the entire growing season (spring into early fall)

(Warriner and Hutchins 2016). Although an important component for rare grassland-dependent skippers, bunchgrasses should not be allowed to dominate range enhancement sites. Seeding rates of native bunchgrasses should be less than seeding rates of forbs. Planting in the fall, rather than spring, will also favor forb development over grasses. In dryer regions including Colorado's Front Range, where precipitation averages $\leq$ 20 inches/year, flowering herbaceous annual and perennial plant species should make up at least 50% of a seed mix, as measured by seeds per square foot. Native grasses should account for no more than 50% of the mix (Warriner and Hutchins 2016). Butterfly enhancement sites should include a minimum of at least three native plant species flowering in each of three blooming periods (spring, summer, and fall), including native plants that bloom during dry summer months (Warriner and Hutchins 2016). Some periodic weed control may be needed in sites converted to native plant communities to assist in the establishment of desirable native plant species.

Riparian management should include fencing habitat to either completely or partially defer grazing by livestock while offering alternate watering sites. Deferment of grazing from early-spring to fall is preferred (Warriner and Hutchins 2016). Establishing site-suitable flowering annual and perennial native herbaceous plants, shrubs, and/or trees along streams or spring margins can provide foraging opportunities for native butterflies and reduce erosion (Warriner and Hutchins 2016). These plantings should include a mix of native plants that provide a succession of flowers from spring, summer, into early fall.

Recreation

Recreation can result in habitat fragmentation and needs consideration from natural resource managers of open space lands, where protection of native butterflies is a management goal. Problems associated with recreation and butterfly diversity include trampling of host and nectar plants by humans and pets and introductions of weeds (Bonte and Maes 2008, Daniels 2015). Trails are vectors for weeds that in time can out-compete natives (Potito and Beatty 2005). Eventually, invasive plants can dominate the landscape causing a decline in integrity of the native plant associations. Avoiding such an outcome is necessary if butterfly conservation is a management goal.

Agriculture

Haying should be restricted to fall through early spring to maximize availability of flowering plants for native butterflies (Warriner and Hutchins 2016). Avoid haying too low, as butterfly larvae and eggs tend to be present during summer, and in a physiological state of diapause during winter, in ground-level vegetation and thatch (Warriner and Hutchins 2016). Instead, maintain a minimum cutting height of six to eight inches. If haying must be conducted during the growing season, leave blocks or strips uncut to retain some stands of flowers and to protect larval populations. Avoid the application of chemical fertilizers, or use “spot” application on specific patches of non-native plants, as these can increase the growth of nonnative grasses and weeds to the detriment of annual and perennial wildflowers.

Weeds

The management and control of invasive plant species is critical to maintaining the integrity of the habitat upon which butterflies depend. However, understanding the degree of disturbance and restoration potential of a site is also critical (Pearson and Otega 2009). Many weed control efforts result in replacement of noxious weeds by the same or other noxious weeds (especially non-native rhizomatous grasses like smooth brome – which actually reduce benefits to wildlife and are difficult if not impossible to restore) because the underlying reason for the existence of weeds has not been addressed (Pearson and Otega 2009). Weed treatment in a natural setting is much more complicated than in an agricultural setting. Control should begin with the least harmful process (hand pulling or seed head removal) (Pearson and Otega 2009). Biocontrol may be an option for some invasive species, however consultation with experts, both botanists and zoologists is always warranted when considering the use of chemicals and/or biocontrol (Hiebert and Stubbendieck 1993). Decisions should be made on a site-by-site basis to prevent (or minimize) negative impacts to non-target butterfly species. Effort should be focused on preventing new introductions and preventing the spread of invasive non-native plants already present (Pearson and Otega 2009). Site plans should be completed before a treatment begins, including a plan to monitor the success of, and need for, treatments (Tu et al. 2001). Some landscapes with weeds may not require treatments (weed cover is low and native cover is high). Once certain species become established (e. g. smooth brome) they are extremely hard to control without increasing the disturbance and weed footprint.

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Table 1. The habitats sampled and the number of visits per transect for each year sampled on OSMP transects in Boulder County, Colorado for the sample years 2002, 2007, 2008, 2015, and 2016.

Habitat type	Sample Year				
	2002	2007	2008	2015	2016
Foothills Grassland	3	6	6	3	3
Foothills Riparian	3	6	6	3	3
Grassland	3	6	6	3	3
Montane Woodland	3	6	6	3	3
Prairie Riparian	3	6	6	3	3
Tallgrass	3	6	6	3	3

Table 2. Formulas used to calculate the diversity measures analyzed on OSMP transects in Boulder County, Colorado for the sample years 2002, 2007, 2008, 2015, and 2016.

Metric	**Traditional Formula**[1]	**Formula for Finite Populations**[2]
Richness	$\frac{\sum_{i=1}^{s}(\mathrm{m}_i)}{3}$	na
Shannon's diversity (H)	$H - \sum_{i=1}^{s}(\mathrm{p}_i)(\ln \mathrm{p}_i)$	na
Simpson's diversity (1 - D)	$1 - \sum_{i=1}^{s}(\mathrm{p}_i^2)$	$1 - \sum_{i=1}^{s}\frac{n_i(n_i-1)}{N_i(N_i-1)}$

[1] $\boldsymbol{s}$ = number of species, $\mathbf{m}_i$ = the number of species recorded during the ***i***th month, and $\mathbf{p}_i$ = proportion of total sample belonging to ***i***th species.
[2] equation used for the value of *D* reported here: $\boldsymbol{n_i}$ = total number of individuals of the ***i***th species and $\boldsymbol{N_i}$ = total number of individuals of all species.

Table 3. Mixed effects repeated measures ANOVA comparing Species richness on habitat type, year, and the habitat type by year interaction on OSMP transects in Boulder County, Colorado for the sample years 2002, 2007, 2008, 2015, and 2016 (* $p \leq 0.05$, ** $p \leq 0.01$).

Source	**Df**	**Sum Sq**	**Mean Sq**	**F value**	**Pr(>F)**
Between-subjects					
Habitat	5	487.4	97.5	5.3	0.008**
Residuals	12	220.8	18.4		
Within-subjects					
Year	1	178.0	178.0	41.8	0.00003**
Habitat:Year	5	109.0	21.8	5.1	0.01*
Residuals	12	51.1	4.3		

Table 4. Results of Tukey's multiple comparisons of means test performed on species richness, among the six habitat types on OSMP transects in Boulder County, Colorado for the sample years 2002, 2007, 2008, 2015, and 2016 (* $p \leq 0.05$, ** $p \leq 0.01$).

Habitat Comparison[1]	**Mean 1**	**Mean 2**	**t.ratio**	**P adj**
FG-FR	8.1	12.7	-2.9	0.1075
FG-GL	8.1	5.0	2.0	0.4
FG-MW	8.1	3.4	0.9	1.0
FG-PR	8.1	6.8	0.9	1.0
FG-TG	8.1	7.8	0.2	1.0
FR-GL	12.7	5.0	4.9	0.004**
FR-MW	112.7	3.4	3.9	0.06
FR-PR	112.7	6.8	3.7	0.03*
FR-TG	112.7	7.8	3.1	0.08
GL-MW	5.0	3.4	-1.617	0.6
GL-PR	5.0	6.8	-1.1	0.9
GL-TG	5.0	7.8	-1.9	0.51
MW-PR	3.4	6.8	0.9	1.0
MW-TG	3.4	7.8	-0.9	1.0
PR-TG	6.8	7.8	-0.6	0.99

[1] FG = Foothills Grassland, FR = Foothills Riparian, GL = Grassland, MW = Montane Woodland, PR = Prairie Riparian, and TG = Tallgrass

Table 5. Results of Tukey's multiple comparisons of means test performed on species richness, among the five sample years on OSMP transects in Boulder County, Colorado for the sample years 2002, 2007, 2008, 2015, and 2016 (* $p \leq 0.05$, ** $p \leq 0.01$).

Year Comparison	**Mean 1**	**Mean 2**	**t.ratio**	**P adj**
2002-2007	8.2	10.2	-2.3	0.16
2002-2008	8.2	10.6	-2.7	0.062
2002-2015	8.2	5.6	3.0	0.03*
2002-2016	8.2	5.5	3.1	0.022*
2007-2008	10.2	10.6	-0.4	0.99
2007-2015	10.2	5.6	5.3	<0.0001**
2007-2016	10.2	5.5	5.4	<0.0001**
2008-2015	10.6	5.6	5.7	<0.0001**
2008-2016	10.6	5.5	5.8	<0.0001**

Table 6. Mixed effects repeated measures ANOVA comparing Shannon's diversity index on habitat type, year, and the habitat type by year interaction on OSMP transects in Boulder County, Colorado for the sample years 2002, 2007, 2008, 2015, and 2016 (* $p \leq 0.05$, ** $p \leq 0.01$).

Source	**Df**	**Sum Sq**	**Mean Sq**	**F value**	**Pr(>F)**
Between-subjects					
Habitat	5	13.4	2.7	6.8	0.003**
Residuals	12	4.7	0.4		
Within-subjects					
Year	1	1.4	1.4	14.1	0.003**
Habitat:Year	5	0.9	0.1	1.5	0.25
Residuals	12	1.2	0.1		

Table 7. Results of Tukey's multiple comparisons of means test performed on Shannon's diversity index, among the six habitat types on OSMP transects in Boulder County, Colorado for the sample years 2002, 2007, 2008, 2015, and 2016 (* $p \leq 0.05$, ** $p \leq 0.01$).

Habitat Comparison[1]	**Mean 1**	**Mean 2**	**t.ratio**	**P adj**
FG-FR	1.49	1.84	-1.5	0.7
FG-GL	1.49	1.06	1.9	0.4
FG-MW	1.49	1.06	-0.4	1.0
FG-PR	1.49	0.67	3.6	0.03*
FG-TG	1.49	1.49	0.03	1.0
FR-GL	1.84	1.06	3.4	0.05*
FR-MW	1.84	1.60	1.1	0.9
FR-PR	1.84	0.67	5.1	0.003**
FR-TG	1.84	1.49	1.5	0.6
GL-MW	1.06	1.60	-2.4	0.2
GL-PR	1.06	0.67	1.7	0.6
GL-TG	1.06	1.49	-1.9	0.5
MW-PR	1.606	0.67	4.0	0.02*
MW-TG	1.60	1.49	0.5	1.0
PR-TG	0.67	1.49	-3.6	0.04*

[1] FG = Foothills Grassland, FR = Foothills Riparian, GL = Grassland, MW = Montane Woodland, PR = Prairie Riparian, and TG = Tallgrass

Table 8. Results of Tukey's multiple comparisons of means test performed on Shannon's diversity index, among the five sample years on OSMP transects in Boulder County, Colorado for the sample years 2002, 2007, 2008, 2015, and 2016.(* $p \leq 0.05$, ** $p \leq 0.01$).

Year Comparison	**Mean 1**	**Mean 2**	**t.ratio**	**Padj**
2002-2007	1.44	1.59	-1.1	0.8
2002-2008	1.44	1.37	0.4	1.0
2002-2015	1.44	1.19	1.7	0.4
2002-2016	1.44	1.19	1.7	0.4
2007-2008	1.59	1.37	1.5	0.6
2007-2015	1.59	1.19	2.8	0.05*
2007-2016	1.59	1.19	2.8	0.05*
2008-2015	1.38	1.19	1.3	0.7
2008-2016	1.38	1.19	1.3	0.7
2015-2016	1.19	1,19	-0.1	1.0

Table 9. Mixed effects repeated measures ANOVA comparing Simpson's diversity index on habitat type, year, and the habitat type by year interaction on OSMP transects in Boulder County, Colorado for the sample years 2002, 2007, 2008, 2015, and 2016.(* $p \leq 0.05$, ** $p \leq 0.01$).

Source	**Df**	**Sum Sq**	**Mean Sq**	**F value**	**Pr(>F)**
Between-subjects					
Habitat	5	1.8	0.4	7.8	0.002**
Residuals	12	0.5	0.05		
Within-subjects					
Year	1	0.1	0.1	41.7	0.2
Habitat:Year	5	0.2	0.03	0.6	0.7
Residuals	12	10.3	0.9		

Table 10. Results of Tukey's multiple comparisons of means test performed on Simpson's diversity index, among the six habitat types on OSMP transects in Boulder County, Colorado for the sample years 2002, 2007, 2008, 2015, and 2016.(* $p \leq 0.05$, ** $p \leq 0.01$).

Habitat Comparison[1]	**Mean 1**	**Mean 2**	**t.ratio**	**P adj**
FG-FR	0.74	0.76	-0.3	1.0
FG-GL	0.74	0.57	1.9	0.5
FG-MW	0.74	0.74	-0.05	1.0
FG-PR	0.74	0.36	4.5	0.008**
FG-TG	0.74	0.66	0.9	0.9
FR-GL	0.76	0.57	2.1	0.3
FR-MW	0.76	0.74	0.2	1.0
FR-PR	0.76	0.36	4.7	0.005**
FR-TG	0.76	0.66	1.2	0.8
GL-MW	0.57	0.74	-1.9	0.4
GL-PR	0.57	0.36	2.6	0.2
GL-TG	0.57	0.66	-0.9	0.9
MW-PR	0.74	0.36	4.5	0.007**
MW-TG	0.74	0.66	1.0	0.9
PR-TG	0.36	0.66	-3.5	0.04*

[1] FG = Foothills Grassland, FR = Foothills Riparian, GL = Grassland, MW = Montane Woodland, PR = Prairie Riparian, and TG = Tallgrass

Table 11. Results of Tukey's multiple comparisons of means test performed on Simpson's diversity index, among the five sample years on OSMP transects in Boulder County, Colorado for the sample years 2002, 2007, 2008, 2015, and 2016.(* $p \leq 0.05$, ** $p \leq 0.01$).

Year Comparison	**Mean 1**	**Mean 2**	**t.ratio**	**Padj**
2002-2007	0.68	0.70	-0.25	1.0
2002-2008	0.68	0.60	1.05	0.8
2002-2015	0.68	0.62	0.71	1.0
2002-2016	0.68	0.60	1.02	0.8
2007-2008	0.70	0.60	1.30	0.7
2007-2015	0.70	0.62	1.0	0.9
2007-2016	0.70	0.60	1.27	0.7
2008-2015	0.60	0.62	-0.34	1.0
2008-2016	0.60	0.60	-0.03	1.0
2015-2016	0.62	0.60	0.31	1.0

Figure 1. Map of the study area, City of Boulder Open Space and Mountain Parks (OSMP), Boulder, Colorado. The map illustrates the habitat types of the transects and their geographic location on OSMP properties, where butterflies were sampled from June to August in 2002, 2007, 2008, 2015 and 2015.

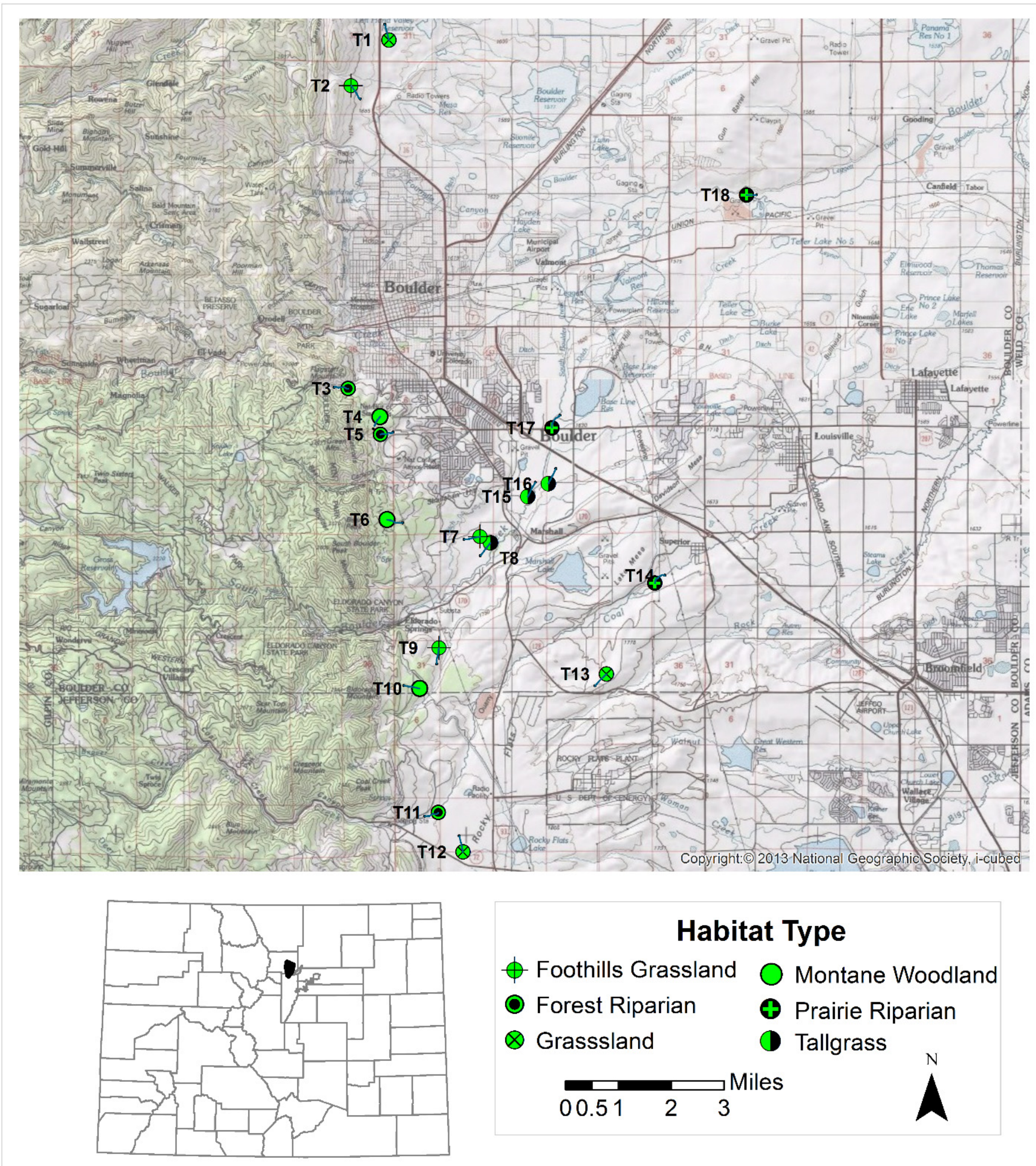
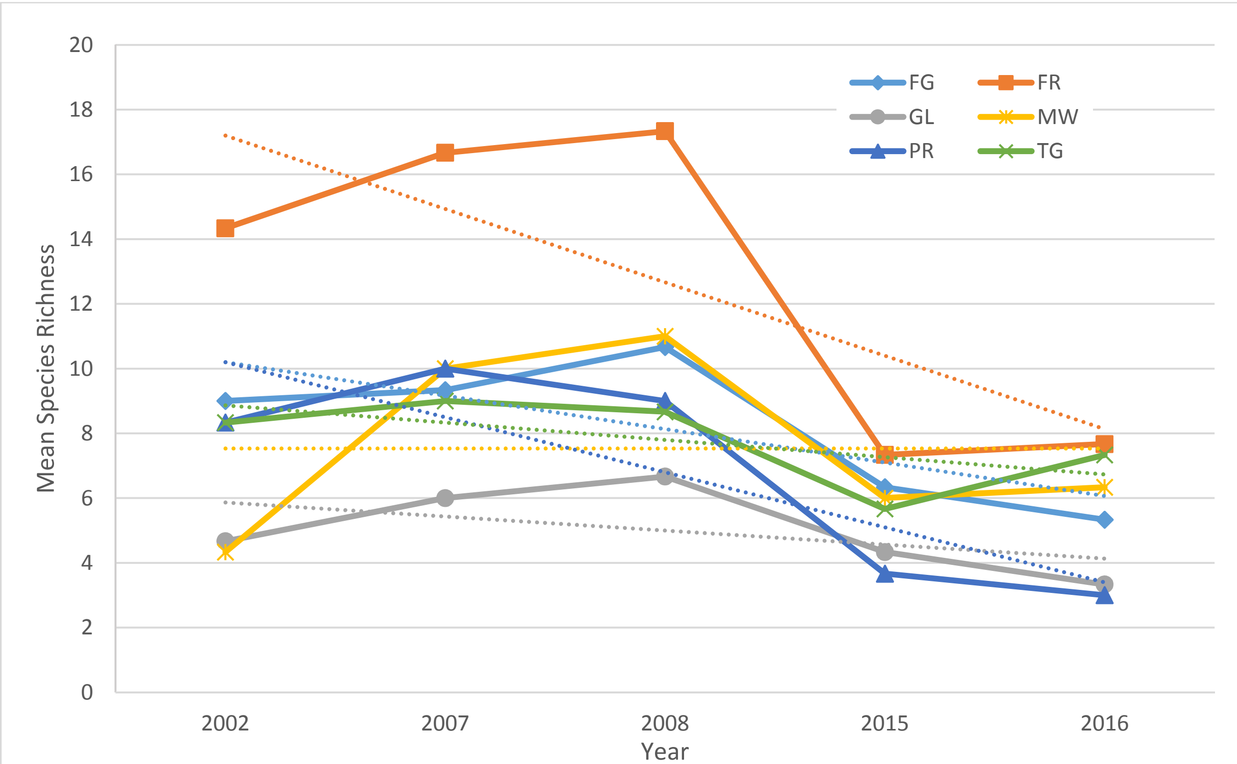
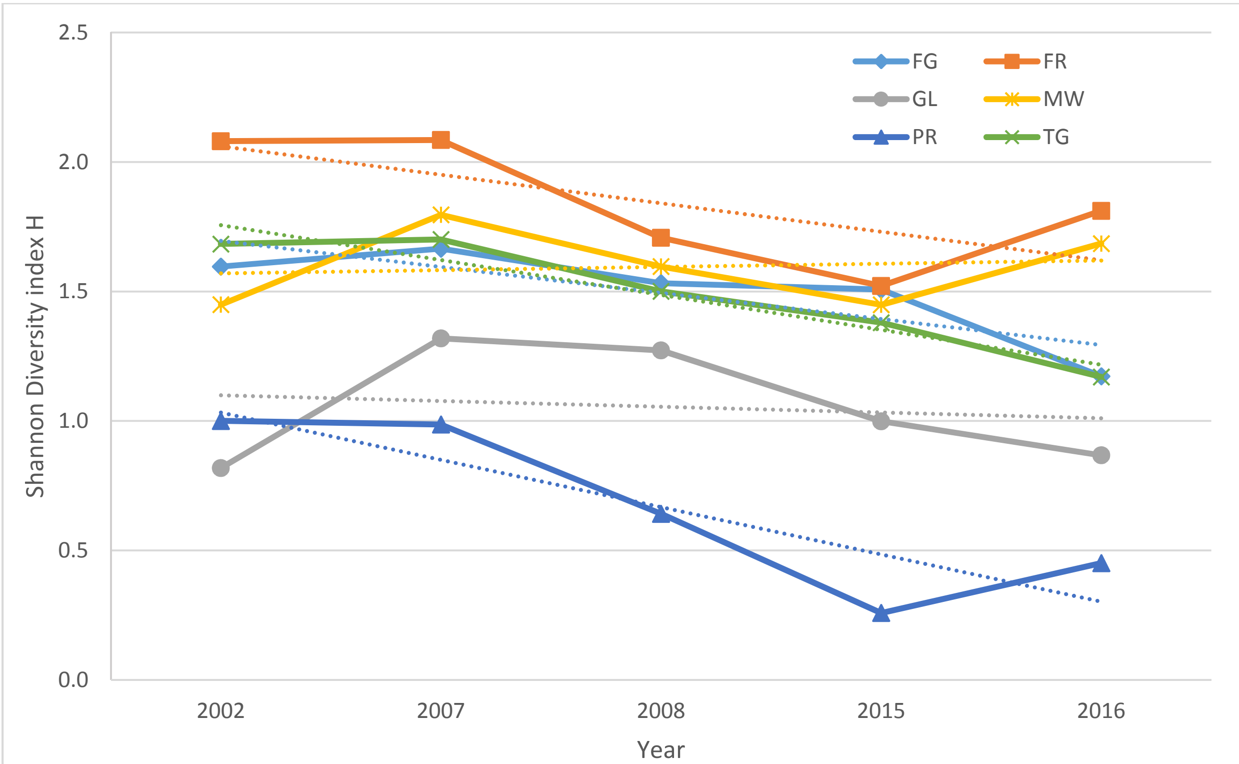


Figure 2. Mean butterfly species richness over time and by habitat type[1] with the linear trend line for each habitat type displayed.



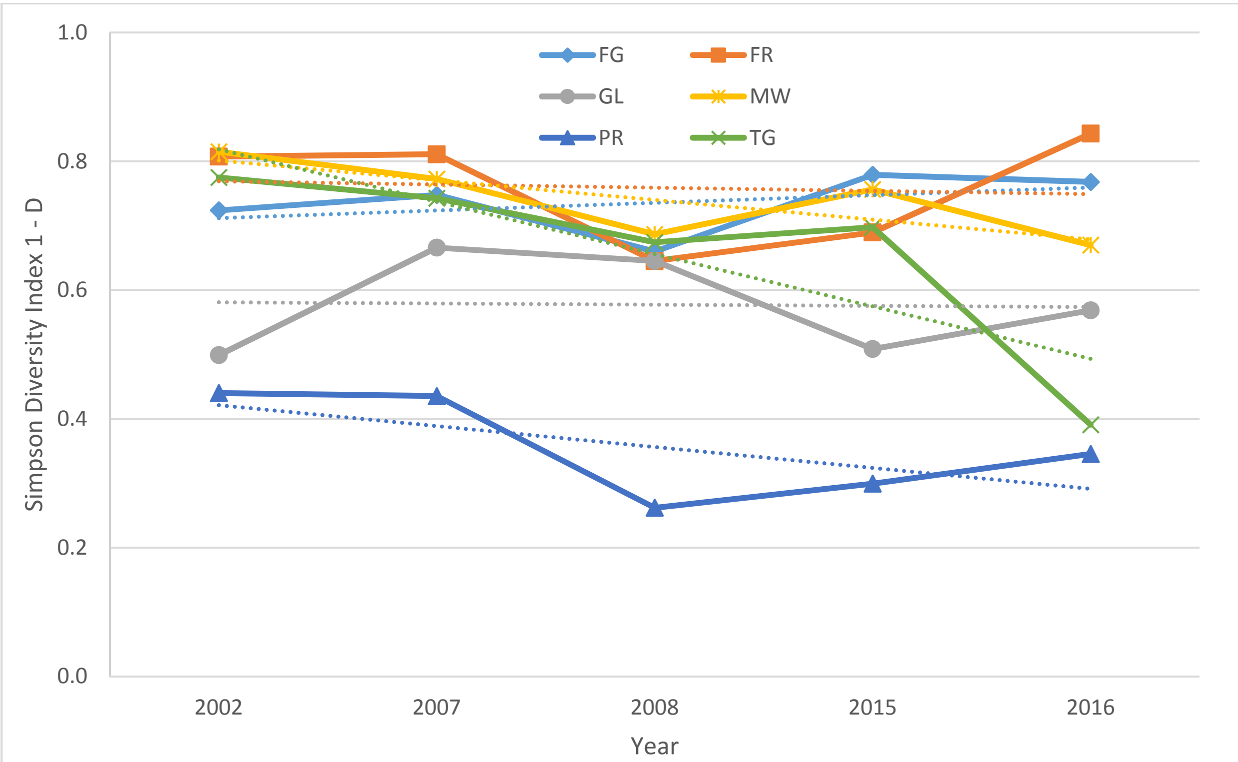
[1] Habitat type: FG = foothill grassland, FR = foothill riparian, GL = grassland, MW = montane woodland, PR = prairie riparian, and TG = tallgrass.

Figure 3. Mean values of the Shannon's *H* diversity index for the butterfly community over time and by habitat type[1] with the linear trend line for each habitat type displayed.



[1] Habitat type: FG = foothill grassland, FR = foothill riparian, GL = grassland, MW = montane woodland, PR = prairie riparian, and TG = tallgrass.

Figure 4. Mean values of the Simpson's diversity index for the butterfly community over time and by habitat type[1] with the liner trend line for each habitat type displayed.



[1] Habitat type: FG = foothill grassland, FR = foothill riparian, GL = grassland, MW = montane woodland, PR = prairie riparian, and TG = tallgrass.