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Once-yearly sampling for the detection of trends in biodiversity: The case of Willow Slough, California

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ABSTRACT

The butterfly fauna at Willow Slough, Yolo County, California has been censused for 32 years as part of a participatory citizen-science project, the Fourth of July Butterfly Count. While the utility of a once-a-year census as a monitoring tool is potentially compromised by lack of standardization in counting protocols and variation in observer skill, at Willow Slough these issues have been minimized.

We examined the Willow Slough count data for trends in both faunal diversity and the probability of presence of individual species. During the study, the number of species observed at a visit declined by 39%. Regressions of per-visit species counts against time did not detect a statistically significant decline until year 24. In contrast, Fisher's α, a statistic designed to reduce sample-size bias, detected the decline as early as year 13. Twelve of the 24 species analyzed showed significant declines in probability of occurrence; a further nine exhibited negative but non-significant trends. Butterflies that overwinter as eggs or larvae were more likely to decline than those that overwinter as pupae or adults. Many species in decline at Willow Slough have also been observed less frequently at nearby sites which are monitored year-round, supporting the value of once-a-year monitoring. Although correlations with climatic data have been identified, they are too weak to account for the observed faunal decline. We suspect broader patterns of land use and habitat continuity are implicated in butterfly declines across the region.

We conclude that once-a-year sampling, if properly and rigorously done, is in fact useful as a monitoring tool for butterfly faunas, and that Fisher's α is well suited to early detection of trends in repeated diversity sampling.

1. Introduction

Concerns about biodiversity loss and global change have triggered an upsurge of interest in "citizen science". Members of the public, often already-committed amateur naturalists, are enlisted to monitor populations or biota in the hope of spotting trends in time for intelligent action to be taken (Lundmark, 2003; Silvertown, 2009). One of us (MLR) has mentored such an effort in hopes that anthropogenic habitats—including cities—would not be forgotten (www.tucsonbirds.org; Anonymous, 2009; McCaffrey, 2005; Turner, 2003). Such projects can generate long-term data sets that may contribute to our recognizing larger-scale trends.

In North America, the annual Audubon Christmas Bird Count is the best-known example, and it has spawned imitators, of which one of the oldest is the Fourth of July Butterfly Count (Kocher and Williams, 2000; Swengel, 1990). This continent-wide activity was begun by the Xerces Society in 1975 and is now administered by the North American Butterfly Association (NABA) (Wander, 2009; at www.naba.org). In recent years NABA has included from 400 to 500 counts, each with several participants. In its description of the program, NABA claims (Wander, 2009, p. iv) that "Count results provide abundant information about the distribution and relative population sizes of butterflies. Comparisons across years can be used to monitor changes in populations and study the effects of weather and habitat changes on butterflies." But of course, from a statistical perspective such claims are fraught with reservations. How comparable are the data either among routes or among years within routes? This is an issue of standardization and quality control. Although NABA provides a framework for the conduct of counts, there are numerous potential sources of error. The least-likely major source of error is variation in sampling route or coverage, since counters are admonished to standardize this. On the other hand, the number of counters may vary significantly from year-to-year, along with their degree of skill in field identification (a significant issue in many butterfly

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groups). Moreover, NABA allows a leeway of several weeks in count scheduling (merely centered on the fourth of July). Not only can sampling date introduce error; it may also interact with weather-driven year-to-year phenological variation to create a false impression of change in population size (Tryjanowski and Sparks, 2001). These issues might be partially addressed post hoc by multivariate statistical analysis, assuming climatological data are available, but this has not been routinely done. Until it is, apparent trends in the 4th of July data are merely suggestive. These issues are recognized for most if not all "citizen science" projects, and are coming under increased scrutiny by biostatisticians and conservation biologists (Link and Sauer, 1996; Link et al., 2006).

There is one 4th of July survey route designed to obviate as many of these problems as possible. One of us (AMS), beginning in 1977 and continuing to the present, has carried out a count at Willow Slough, Yolo County, California alone, using absolutely standardized protocols. In just one year, 1989, the count was done by a surrogate who, like AMS, was already a seasoned lepidopterist who had extensive experience with the local fauna. The count has always been on July 4, a fact made possible by the Mediterranean climate of the California Central Valley which virtually assures good weather. Standardization of method also should minimize species detectability as an issue. Thus Willow Slough can serve as a test of what information of conservation value—if any—can be extracted from a once-a-year butterfly-monitoring regime under the best of circumstances.

Willow Slough is also unusual in another way. Since 1972, AMS has been monitoring entire butterfly faunas along a transect covering 10 sites including several in the region of Willow Slough. Sites along the Shapiro California transect (http://butterfly.ucdavis.edu) are sampled biweekly throughout the year, using the same protocol as at Willow Slough. One of these sites, West Sacramento, sampled since 1988, is <15 km from Willow Slough at similar elevation and shares most of the same butterfly fauna. The record of flight timing at West Sacramento provides a check on whether apparent population changes at Willow Slough might actually be byproducts of regional variations in seasonal phenology. It also allows comparisons of apparent population trends through time at Willow Slough, sampled only once-a-year, to the performance of populations of the same species at the much-more-closely-monitored West Sacramento site over extended periods. Long-term (>25 year) butterfly monitoring datasets, of sufficient length to detect declines in diversity at specific locations, are rare, being essentially limited to the British Butterfly Monitoring Scheme (Pollard and Yates, 1993). Similar schemes have begun in the Ukraine (1983), in Germany (1989), in the Netherlands and Finland (1990), in Belgium (1991), and in Spain (1994) (Marttila et al., 2001; van Swaay et al., 2008).

This study presents an analysis of a 32-year record of butterfly species diversity at Willow Slough. We asked, has butterfly species diversity at Willow Slough changed over the past 32 years? If so, by how much? The raw number of species observed in a sample (here referred to as "species count"), depends strongly on sample size, the number of individuals encountered. It is thus a relatively poor estimator of species diversity (Gotelli and Colwell, 2001), the actual number of species in a fauna, a quantity often referred to elsewhere as "species richness". Sample size in our data set varied considerably, so we estimated relative species diversity using Fisher's alpha, a bias-reducing index of species diversity that was designed to facilitate comparison between samples of different sizes (Fisher et al., 1943; Rosenzweig, 1995). A second goal of our study was to compare the sensitivity with which trends in the fauna were detected using alpha versus raw species counts.

Butterflies are sensitive to weather conditions, leading to their frequent appearance in studies of the biotic impacts of climate change (Hellmann et al., 2008; Parmesan and Yohe, 2003; Wilson et al., 2007). The third goal of the paper was to assess whether observed changes in species diversity (as estimated by species counts and by Fisher's alpha) and abundance were associated with variation of local weather variables.

The assemblage-level metrics mentioned so far give no indication of which species have been observed with decreasing or increasing frequency. The paper's final goal was to determine which butterfly species were increasing or decreasing in probability of occurrence and to test whether butterfly life history attributes predicted the species' trends.

2. Materials and methods

2.1. Study site

Willow Slough (38 37 40 N, 121 44 00 W, elevation 15 m) is a partly-channelized perennial stream located 3.5 km north of Davis, Yolo County, CA. The area was seasonal wetland prior to agriculturalization in the 19th Century (Shapiro, 2009; Thompson, 1960). Beyond the levees enclosing the floodplain row crops and alfalfa are grown today. The ungrazed floodplain contains both woody and herbaceous riparian and wetland vegetation. The woody vegetation is periodically removed manually because it impedes free flow in winter. The herbaceous vegetation is very dynamic due to periodic inundation and sedimentation, but is dominated by perennials, many of which are clonal and form large patches. It is documented narratively each year and photographically from time to time, but no quantitative vegetation sampling has been done. The makeup of the perennial vegetation has changed dramatically over time, as discussed elsewhere in this paper. The vegetation on the levees, which are kept free of woody plants, consists mainly of naturalized annual grasses and forbs, which are burned annually after drying commences in late spring or early summer.

2.2. Sampling

AMS walks a standardized 11-km course, originally laid out in 1977 to maximize habitat coverage, in one direction only, requiring 5.5–6 h. His sampling protocol is essentially identical to the "Pollard Walk" used in the U.K. Butterfly Monitoring Scheme (Pollard and Yates, 1993), except that in the "Pollard Walk" only butterflies within a 5 m "box" ahead of and to the sides of the observer are counted. In contrast, AMS counts to the limits of his visual acuity in those directions, generally beyond 5 m. The course has been held constant despite changes in the vegetation. In all 4th of July counts the observer records weather conditions at the start and end of the count, but for our analyses we use the University of California/National Oceanic and Atmospheric Administration climate station in Davis, California (38 32 07 N, 121 46 30 W); the observation site is 7 km SSW of Willow Slough. Because extreme afternoon heat may cause butterflies to seek shelter and be unobservable, the count is begun 15–30 min earlier on days expected to exceed 35 °C.

2.3. Analysis of faunal diversity

Because the number of butterflies seen at Willow Slough varies considerably, we were concerned that year-to-year variation in sample size might introduce enough noise to obscure any underlying trend in species diversity of the fauna. We thus calculated Fisher's alpha (α), the oldest bias-reducing statistic (Fisher et al., 1943), for each year's data using the R package "vegan" (Oksanen et al., 2010), and compared the results of analyses carried out using α with those that used raw species counts.

Fisher's α is calculated by solving the following non-linear equation: