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LONG-TERM POPULATION MONITORING OF THE KARNER BLUE (LEPIDOPTERA: LYCAENIDAE) IN WISCONSIN, 1990-2004

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ABSTRACT

We monitored Wisconsin populations of the Karner blue (*Lycaeides melissa samuelis* Nabokov, Lepidoptera: Lycaenidae) during 1990-2004. We surveyed consecutive spring and summer broods in two contiguous central Wisconsin counties (Jackson, Wood), starting with three sites in summer 1990 and expanding to 14 sites by summer 1996 ("constant-site monitoring"). In northwestern Wisconsin (Burnett County), we started constant-site monitoring of consecutive summer broods with 11 sites in 1991, expanding to 15 sites by 1998. Population indices (Karner blue individuals per km on peak survey per site per brood) from constant sites were positively and significantly correlated with comparable indices for the same broods from "non-constant sites" (all other Karner blue sites we surveyed, which changed in number and location in each brood). The non-constant-site indices for summer 1998-2003 from the statewide Habitat Conservation Plan (HCP) had no significant correlations with our constant-site and non-constant-site indices, or with constant-site indices from Fort McCoy (Monroe County, central Wisconsin). Fort McCoy indices had many significant correlations (all positive) with our constant-site indices, biased toward our indices from nearer sites, but not with our non-constant-site indices. Correlations using both spring and summer indices produced more significant effects than the same tests using only summer or spring broods. Burnett County indices never correlated significantly with indices from central Wisconsin counties ca. 250 km away, while indices from the central Wisconsin counties often covaried significantly. Thus, datasets comprising constant-site indices with >6 years of surveys sampling both spring and summer broods had greater statistical power and showed stronger covariances among nearer sites.

Brood size varied more in consecutive springs than consecutive summers, and the larger the geographic scale of an index, the lower this variability was. The longer the time period sampled, the larger the coefficients of variation (CV) for the mean of the indices per site, so that monitoring for shorter time periods would underestimate Karner blue population variability.

For tests of trend (correlation of indices with year) with $P < 0.10$, the sign of the coefficient was always the same for a given group of sites, no matter the type of correlation (linear or non-parametric), type of index (three-year running average or individual brood), or set of seasons used (spring and/or summer). Correlations using only summer indices or using both spring and summer indices produced similar levels of significance. Correlations using only spring indices produced fewer significant results. We classified our sites by management class used in the HCP: "shifting mosaic" (SM, in forest succession) and "permanency of habitat" (PH, rights-of-way not in succession). "Reserve" (R) had management activities exceeding the minimum required by the HCP, akin to nature reserve management. R sites had non-significant or positive near-significant trends. SM and PH had many negative significant and near-significant trends, both for fewer sites over more years and more sites for fewer years. SM sites had no tree-cutting during this study, and Karner blue abundance negatively relates to forest canopy. Conversely, routine mowing and brush-cutting in PH sites are favorable for Karner blues. But most PH sites also experienced soil-exposing events in 1996 and/or 2000-2004 that destroyed vegetation. At Crex Meadows, Karner blues appeared to increase more in the permanent non-fire refugium

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than at other sites there, which continued in fire management with modifications favorable for Karner blues but both the refugium and other sites had similar positive significant trends.

The Karner blue (*Lycaeides melissa samuelis* Nabokov, Lepidoptera: Lycaenidae) is restricted to eastern North America. It has two complete life cycles per year (spring and summer "broods" or generations), feeds only on wild lupine (*Lupinus perennis* L., Fabaceae) as a larva, and overwinters as an egg. This butterfly has a geographically narrow generally east-west historical range at the northern end of lupine range, from eastern Minnesota through the Great Lakes states and southern Ontario to New England (Iftner et al. 1992, Bleser 1993, Dirig 1994, Packer 1994, Savignano 1994).

The Karner blue was federally listed as endangered in the U.S. in December 1992 (U.S. Fish and Wildlife Service 2003) and considered extirpated in Canada. This butterfly has never had legal protection in Wisconsin at the state level. A federal recovery plan for the Karner blue was approved in 2003; many recovery activities started before then. Critical habitat has not been designated, but five recovery units (regions) have been established in Wisconsin, although specific recovery activities in these units were not identified.

Also pursuant to federal listing, a Habitat Conservation Plan (HCP) for Wisconsin was approved in September 1999 (Wisconsin Department of Natural Resources 2000, Carter 2002). The federal listing in 1992 immediately reduced the range of legal activities (e.g., for roadside management and timber harvest) in locations occupied by the butterfly, more so before than after HCP approval. The HCP defines the minimum legal requirements for landowners of Wisconsin Karner blue localities. Land uses are not required to achieve recovery of the butterfly but must meet the lesser standard that they will be activities "with consideration for the Karner blue butterfly and its habitat" or "will not appreciably reduce the likelihood of the survival and recovery of the Karner blue butterfly in the wild".

In the HCP, occupied sites are categorized as either "shifting mosaic" (SM) or "permanency of habitat" (PH). SM sites, primarily in timber management, proceed through forest succession, with the Karner blue expected to decline as trees shade out wild lupines. But as forested sites are cleared of trees, the Karner blue is expected to colonize wild lupines regenerating in cut sites. PH locations, such as roadsides and power line rights-of-way, are managed to remain non-canopied in ways not harmful to Karner blues. Many HCP activities began well before plan approval, and management activities at some sites exceed the minimum required by the HCP, so as to become "sites to feature, protect, or enhance the Karner blue butterfly and its habitat" (i.e., akin to nature reserve management and recovery activities).

In this paper, we analyze our 15 years of Karner blue surveys in central and northwestern Wisconsin. Although selected prior to federal listing and/or HCP approval, our monitoring sites represent the three management categories: shifting mosaic, permanency of habitat, and reserve (i.e., where recovery would be expected to occur).

Surveying and monitoring are necessary components of conservation programs for rare or declining butterfly species (Dennis 1993, Pollard and Yates 1993). As a result, much effort in the U.S. and Canada has been devoted to surveying and monitoring Karner blues (e.g., many papers in Andow et al. 1994, Brown and Boyce 1998). The assessment of a butterfly's status and trend is greatly confounded by large variability among broods attributable to fluctuations in abundance due to climate and other factors (Dennis 1993, Pollard and Yates 1993).

In this paper, we (1) test for consistency in population indices, by correlating indices within subregion among different samples of sites; (2) compare indices between "constant sites" (location and number of sites held constant among broods) and "non-constant sites" (all other Karner blue sites we surveyed in the same broods; these sites changed in number and location in each brood); (3) correlate indices from our surveys to those from other monitoring programs in Wisconsin; (4) test the usefulness of surveying sites repeatedly within brood for obtaining an index that is the peak survey per brood; (5) correlate constant-site indices among counties, to test for regional variation in annual fluctuation and trend; (6) compare abundance between the spring and summer broods; (7) calculate the (a) short-term variability in broods between consecutive broods and subsequent broods of same season, and (b) long-term variability in indices over the course of the study; and 8) test for trends in the indices by season, by subregion, and by management and land use category, with comparisons of results by whether number of sites or number of years is optimized. Such information should prove useful for designing and interpreting surveys of Karner blue populations, as well as assessing this butterfly's status and trend in Wisconsin.

METHODS

Study sites and surveys

We conducted transect surveys of Karner blue adults in each brood from spring 1990 through summer 2004, with 23,410 individuals recorded in 1147 km of surveys between 13 May and 6 September at a cumulative total of 171 pine-oak barrens in two subregions (and in all five federal recovery units): (1) eight counties (Clark, Eau Claire, Green Lake, Jackson, Juneau, Monroe, Portage, Wood) in central Wisconsin and (2) one county (Burnett) in northwestern Wisconsin (43.93-45.98°N, 89.10-92.74° W) (Fig. 1). It was not possible to visit all sites each year, but we surveyed most sites multiple times both within a year and among years, and surveyed many sites in both subregions each year.

Figure 1. Map of Wisconsin, identifying counties mentioned in this paper.

We surveyed along like routes within each site each visit (similar to Pollard 1977), as described in Swengel and Swengel (1996). All butterfly species found were counted, but survey times and locations were selected to study barrens-specific butterflies, including the Karner blue. Karner blue individuals were sexed, if possible. A new survey unit was designated whenever the habitat along the route varied by management and/or vegetation type. For each unit, we recorded temperature, wind speed, percent cloud cover, percent time sun was shining, route distance, and time spent surveying. Data from each unit were kept separate. Surveys occurred in a wide range of weather and times of day. Occasionally surveys occurred in intermittent light drizzle, so long as butterfly activity was apparent, but not in continuous rain.

In central Wisconsin, we started "constant-site" population monitoring (consecutive-brood surveying of a site) in two contiguous counties (Jackson, Wood) in summer 1990 (N = 3 sites) (Table 1). We added additional monitoring sites in the same counties in spring 1991 (N = 2 sites), spring 1992 (N = 3), spring 1993 (N = 1), spring 1994 (N = 1), spring 1995 (N = 3), and summer 1996 (N = 1). For some sites, we had surveyed them in several non-consecutive broods before consecutive-brood surveying began. We tried to survey all monitoring sites several times within a brood (Fig. 2) to obtain one survey as near to "peak" numbers as possible, but weather and scheduling problems prevented this at a few sites in some broods.

In northwestern Wisconsin, we consistently surveyed Karner blues only in summer. We started with 11 constant sites in summer 1991 (Table 1), with one site added in 1994, one in 1995, and two in 1998. We surveyed these monitoring sites in three spring broods: 12 sites in 1994, 8 of the 15 sites in 1998, and all 15 sites in 2004. We only surveyed on one date per brood (Fig. 2). Our phenological observations in central Wisconsin and elsewhere in northern Wisconsin aided in date selection. Because sex ratio significantly declines during the course of a Karner blue brood (Swengel and Swengel 1996), this offers the opportunity to test for how consistently we timed this one survey date per brood relative to Karner blue phenology. We tested for a systematic change in sex ratio (and therefore phenology of survey date) during the study period with a Spearman rank correlation of sex ratio (percent males of sexed individuals) and year for the 11 sites surveyed 1991-2004. There was no trend in sex ratio ($r = -0.105$, N = 117 unit surveys with any sexed individuals, $P > 0.10$), and the long-term mean percent males for these sites (77.0%) and the other four sites (68.3%) falls within the range (51.2-79.8%) observed on the peak date in summer broods in central Wisconsin (Swengel and Swengel 1996: Table 2).

All constant-site monitoring sites were occupied by Karner blues at the start of population monitoring. The three counties these sites fall in are each in a different federal recovery unit. All sites within a county are nearer to each other (<25 km apart) than to any site in another county (>30 km apart). We did not bias toward large populations in site selection; some sites had few Karner blues when added to this study. Our biases were that the site was known to us and open to public visitation, efficient to travel to relative to sites already in the study (due to clustering of some sites and due to efficient routing among sites), appeared to support Karner blues consistently, and added vegetative and management range to our sample.

Our population index is the peak survey total per site per brood. Nearly all our peak surveys occurred within the weather parameters of the British Butterfly Monitoring Scheme (Pollard and Yates 1993) and the minimum temperature was ≥17ºC for 98% of our peak surveys. Outside the British parameters were seven spring surveys in northwestern Wisconsin with a minimum temperature of 16ºC (not 17ºC) for surveys with <60% sunshine (these seven surveys had 15-50% sunshine). Our peak surveys occurred in a much wider range of times of day (0712-1818 hrs standard time) than in the British program. For comparisons among sites, we standardized the peak count to route distance to

Table 1. Constant-site monitoring sites in central Wisconsin (Jackson and Wood Counties) and northwestern Wisconsin (Burnett County). In central Wisconsin, we surveyed consecutive broods since the first brood surveyed; in northwestern Wisconsin, consecutive summer broods.

Subregion/County/Site	**First brood**	**Type**[1]	**Km**	**Latitude**	**Longitude**
Central Wisconsin					
Jackson County					
Dike 17	1990 summer	R	1.45	44.31	90.564
North Brockway East	1996 summer	SM	0.56	44.32	90.73
South Brockway West 1	1995 spring	R	0.28	44.281	90.742
South Brockway West 4	1991 spring	R	0.40	44.283	90.744
Stanton Roadside	1991 spring	PH	1.69	44.23	90.65
West Castle Mound 2	1992 spring	SM	0.40	44.273	90.764
West Castle Mound 4	1992 spring	SM	0.93	44.273	90.766
West Castle Mound roadside	1994 spring	PH	0.40	44.275	90.765
Wildcat-Spangler NE	1990 summer	SM	0.84	44.2782	90.678
Wildcat-Spangler SE	1993 spring	SM	0.40	44.278	90.678
Wood County					
Highway X east-west	1991 spring	PH	0.97	44.30	90.13
Highway X north-south	1990 summer	PH	1.61	44.34	90.13
Highway X south	1995 spring	PH	0.46	44.32	90.13
Sandhill west field	1995 spring	R	0.56	44.33	90.18
Northwestern Wisconsin					
Burnett County Forest					
Peet Firebreak	1994 spring	SM	0.40	45.905	92.543
Peet Roadside	1995 summer	PH	0.84	45.91	92.545
Crex Meadow Wildlife Area					
James Road	1991 summer	R	0.56	45.875	92.55
Klots Road	1991 summer	R (south), PH (north)	0.64	45.88	92.55
Main Road	1991 summer[2]	R	0.36	45.87	92.55
North Reed Lake East	1991 summer	R	0.48	45.92	92.58
North Refuge Road	1991 summer	R	0.80	45.90	92.60
Overlook Northeast	1991 summer[2]	R	0.32	45.88	92.632
Overlook Northwest	1991 summer[2]	R	0.32	45.88	92.634
Overlook Southeast	1991 summer[2]	R	0.28	45.878	92.632
Overlook Southwest	1991 summer	R	0.44	45.878	92.634
Phantom Prairie	1991 summer	R	0.48	45.83	92.67
Reed Corner	1991 summer	R	0.56	45.905	92.55
Fish Lake Wildlife Area					
Stolte Road unit 1	1998 spring	R	0.28	45.738	92.74
Stolte Road unit 2	1998 spring	R	0.40	45.735	92.74

[1] R = reserve; SM = shifting mosaic (forest succession), PH = permanency of habitat (kept open); in analysis, Klots Road is treated as R.

[2] No sampling in summer 1996 due to inclement weather.

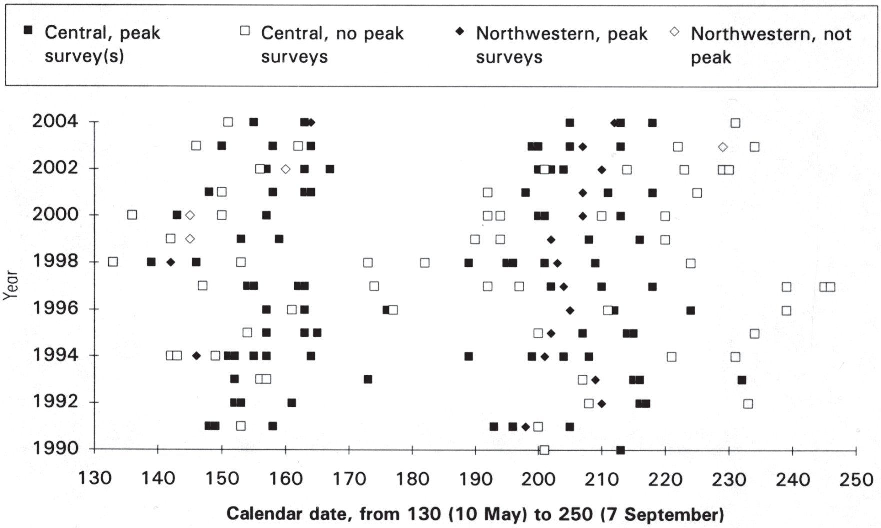

Figure 2. Survey dates during the Karner blue flight period at long-term monitoring sites.

create a rate of observation (or relative abundance) per km that is comparable among sites. Where actual survey totals (not standardized to km) are analyzed, this is so noted. We recorded 13,259 Karner blues in 403 km of peak surveys.

Other monitoring datasets

As part of the HCP, a three-step Karner blue population monitoring program began in 1998 (Carter 2002). First, a random sample of tracts subject to HCP regulation and containing soil types suitable for lupine growth was surveyed for presence of wild lupine. Second, at a random sample of tracts containing lupine, surveys for presence or absence of Karner blues were conducted. Third, at a random sample of tracts that meet minimum lupine abundance thresholds (i.e., different sites each year), Karner blues were counted twice along parallel strip transects seven or more days apart in the summer brood within a specified range of weather and time of day. The population index for each site is the sum of Karner blues on both surveys per km and the statewide index (available for 1998-2003) is the geometric mean of these indices, for all sites and by management category (SM and PH) (Carter 2002, Bernstein et al. 2004). This third step (butterfly transect surveys) did not occur in 2004 (Thibodeaux et al. 2005).

We obtained the unpublished results of Karner blue population monitoring at Fort McCoy, in Monroe County (in the same federal recovery unit with Jackson County) in central Wisconsin. These surveys were conducted along fixed routes (mean 1.9 km; range 0.7-4.5 km) at the same sites each year, starting in summer 1996 (N = 2 sites) and summer 1997 (N = 8 sites). Sites were surveyed repeatedly within brood, often with more surveys per site per brood than we did at our sites, and in consecutive broods through summer 2004, except that no sites were surveyed in spring 1998. As in our dataset, we identified the peak count per site at Fort McCoy per brood, and standardized to survey distance for comparisons among sites. The closest our constant-site monitoring sites come to the Fort McCoy sites is 12 km.

Robert Welch conducted numerous transect surveys along fixed routes at two sites in Portage County (central Wisconsin) in the spring and summer broods

Table 2. Spearman rank correlation coefficients (*r*) of our Karner blue indices per brood with Fort McCoy (Monroe Co.) indices (all sites there lack spring 1998 surveys).

	Spring & summer			**Summer only**			**Spring only**		
	N	***r***	***P***	**N**	***r***	***P***	**N**	***r***	***P*** [1]
Ft. McCoy 10 sites, summer 1997 on[2]									
Central Wisconsin 14 sites	14	+0.864	<0.01	8	+0.786	<0.05	6	+0.829	<0.05
Jackson County 10 sites	14	+0.908	<0.01	8	+0.762	<0.05	6	+0.829	<0.05
Wood County 4 sites	14	+0.705	<0.01	8	+0.667	NS	6	+0.486	NS
Northwestern Wisconsin 9 sites[3]				8	+0.048	NS			
Central & NW Wisconsin				7	+0.857	<0.05			
Central & NW Wisconsin R[4]				7	+0.893	<0.01			
Central & NW Wisconsin PH[4]				7	+0.893	<0.01			
Central & NW Wisconsin SM[4]				8	+0.857	<0.01			
Ft. McCoy 2 sites, summer 1996 on[2]									
Central Wisconsin 14 sites	16	+0.671	<0.01	9	+0.617	NS	7	+0.607	NS
Jackson County 10 sites	16	+0.724	<0.01	9	+0.683	<0.05	7	+0.607	NS
Wood County 4 sites	16	+0.547	<0.05	9	+0.567	NS	7	+0.679	NS
Northwestern Wisconsin 9 sites[3]				9	+0.000	NS			
Central & NW Wisconsin				7	+0.757	<0.05			
Central & NW Wisconsin R[4]				7	+0.857	<0.01			
Central & NW Wisconsin PH[4]				9	+0.583	NS			
Central & NW Wisconsin SM[4]				9	+0.733	<0.05			

[1] NS = $P \geq 0.05$.

[2] Source for dataset provided in "Methods: Other monitoring datasets".

[3] No missing values in summer 1996

[4] R = reserve; SM = shifting mosaic, PH = permanency of habitat.

of 1991-1993 (all data obtained from Welch 1993 and Bleser 1993). Survey distances were not reported, so we used the peak Karner blue count per site as the population index.

Statistical analyses

Analysis was done with ABstat 7.20 software (1994, Anderson-Bell Corp., Parker, Colorado), with statistical significance set at $P < 0.05$. Since significant results occurred much more frequently than would be expected due to Type I statistical errors, we did not lower the P value further, as many more Type II errors would then be created than Type I errors eliminated. Near-significant values up to $P < 0.10$ are also presented, to test further for Type I errors (i.e., near-significant tests that have the same sign as related significant tests indicate more consistency of pattern in a dataset than if the sign is opposite) and to show characteristics of greater or lesser statistical power (e.g., whether longer-term datasets are more likely to obtain significance than shorter-term datasets).

We pooled population indices into a "brood index" (mean of the population indices for all sites in the sample, per brood). Analyses of regional trends require pooling data from multiple sites, to counteract sampling error and site-specific patterns unrepresentative of prevailing regional patterns. If no pooling ever occurs, then site trends are being analyzed one at a time, and each site's representativeness of the region would require extensive substantiation. The nature of the multi-site dataset determines when and how pooling may occur. Most monitoring datasets are confounded by missing values (incomplete time series at the sites, but variation among sites as to which values are missing) and observer variability and turnover. Various analytical techniques are applied first to counteract these confounding factors (not contained in our data). Examples include route-regression, GAM (Generalized Additive Models), and TRIM (Trends and Indices for Monitoring Data) (Geissler and Sauer 1990, Fewster et al. 2000, Conrad et al. 2004). Missing values are minimal in our dataset (absent in most analyses), and we have no observer variability since we collected all the data and were experienced in surveying Karner blues before this study began. Thus, we did not need to apply any preliminary analytical steps prior to pooling (as per Geissler and Sauer 1990). Other examples of analyses that did not require such preliminary analytical steps include analyses of the British Butterfly Monitoring Scheme (Pollard 1977, Pollard 1991, Pollard and Yates 1993) and bird data by Fuller et al. (1995).

Individual site trends might also be calculated first before pooling those trends into a single regional result, to correct for unrepresentativeness of sites (e.g., if 10% of sites occur in the region with 90% of the species' population, then those 10% of sites might be weighted proportionately more in the trend calculation than the other 90% of sites). Although our sites represent a wide range of ownerships and managements (except for industrial forest land), no data are available to us to indicate how our sites should be weighted. Thus, we did not attempt to calculate a representative trend for an entire region. Instead, our pooled index (mean of our sites' population indices for each brood) weights all sites equally, and the trends we calculated with those pooled indices represent only those study sites.

(1) Correlations within subregion among samples of sites: Because our monitoring sites varied as to when consecutive-brood population monitoring started, we had to determine for each analysis whether to use indices from fewer sites but more years, or from more sites with fewer years. Using Spearman rank correlations, we tested in two ways how much the results would differ depending on whether larger or smaller samples of sites were used. First, we correlated the brood indices calculated from increasing pools of sites for the broods common to all sites in the pool. In central Wisconsin, we calculated brood indices for 3, 5, 8, 13, and 14 sites; for northwestern Wisconsin, for 11, 13, and 15 sites. Second, we correlated brood indices calculated from separate cohorts of sites. For central Wisconsin, we calculated these brood indices for summer 1990 on (N = 3 sites), spring 1991 on (N = 2 sites), spring 1992 on (N = 3 sites), and spring 1995 on

(N = 5 sites). For northwestern Wisconsin, we calculated these brood indices for 1991 on (N = 11 sites; 4 sites missing in summer 1996), 1995 on (N = 2 sites), and 1998 on (N = 2 sites).

(2) Comparisons of constant- and non-constant-site indices: In each subregion, we compared our constant-site brood indices to comparable brood indices from "non-constant sites" (all other Karner blue sites we surveyed, which changed in number and location in each brood). The latter is more comparable to the complete annual change in site selection in HCP monitoring. We calculated brood indices for central Wisconsin (spring 1990 on), northwestern Wisconsin (summers only, 1991 on), and combined central and northwestern Wisconsin (spring 1990 on), using the mean of the peak individuals/km for each unit not used for constant-site monitoring. Surveys were within the Karner blue flight period (not necessarily at/near peak) from units where we ever recorded a Karner blue during our study. We used the Spearman rank correlation to test for similarity between constant- and non-constant-site brood indices.

(3) Comparison to other monitoring programs: We used the Spearman rank correlation to compare our constant- and non-constant site brood indices to indices from other datasets in Wisconsin (see "Other monitoring datasets" above). For our constant-site brood indices, we used all sites surveyed in the same broods covered by the other dataset in the correlation. We calculated our indices by county, subregion, region (averaging all surveys in both subregions), and by equal weighting for all counties available (with and without the Fort McCoy dataset covering Monroe County), and by management category (reserve, shifting mosaic, permanency of habitat).

(4) Comparison of additional survey(s) within brood: Separately for our central Wisconsin and Fort McCoy constant-site population indices, we correlated the peak and second highest survey totals per site per brood. We did these correlations separately by whether a third count at that site in that brood was available or not. This is a test of the utility of conducting more counts within a brood to improve the quality of the population index: The more surveys done per brood, the more that the top two counts might both represent peak numbers better.

(5) Correlation among counties: In pairwise Spearman rank correlations, we correlated constant-site brood indices among available counties: Burnett (summer only), Jackson, and Wood Counties in our dataset, and Monroe County in the Fort McCoy dataset.

(6) Comparison of abundance by season: We compared spring and summer survey totals on the peak survey per site, including each year for each site in which both spring and summer broods were surveyed. For comparisons among constant-site datasets and counties, we used the same years for each group in a comparison.

(7) Variability among broods, a) short-term: In our constant-site monitoring, we calculated how much factor change occurred in Karner blue totals within site among consecutive broods (spring to summer, summer to spring) and the same brood between consecutive years (spring to spring; summer to summer), as absolute values (the larger brood / smaller brood). Since these comparisons are within site, we calculated these factors using survey totals, although standardizing to kilometers would be arithmetically similar. When both values in a factor calculation were 0 (rare), we excluded them from all analyses since they create undefined ratios. When one value in a factor calculation was zero and the other positive (creating an infinite ratio), we set the value at 100 but excluded these from means and statistical tests (although their inclusion did not change test results). A ">" before a mean or median indicates infinite ratio(s) were excluded from that calculation. These factors were calculated for individual sites and graduated lumpings of proximate sites, to examine whether variability differs by population size or geographic scale. We used Mann-Whitney U tests to test for differences in mean factor change in consecutive broods (summer to spring, spring to summer), and annually (spring to spring, summer to summer). The samples were eight central Wisconsin sites 1992-2004, 14 central Wisconsin sites 1996-2004, and ten Fort McCoy sites 1998-2004.

7) Variability among broods, b) long-term: We calculated the coefficient of variation (CV) of the population indices to estimate long-term variability in spring and summer indices at constant sites monitored at least six years. We tested for effects of population size on long-term variability using Spearman rank correlations of the mean population index per site with the CV of that mean. We also tested whether shorter monitoring periods exhibited as much variability as longer ones by comparing CVs of indices for the entire survey span to CVs of indices for the first and second halves of that span. Sites analyzed for 1992-2004 were our eight sites in central Wisconsin (spring, summer, both broods) and 11 sites in northwestern Wisconsin (summer only), a total of four samples. For 1998-2004, we analyzed our 14 sites in central Wisconsin (spring, summer, both broods), ten Fort McCoy sites (spring, summer, both broods), and our 14 northwestern Wisconsin sites (summer only; excluding one site lacking a CV in the first half of the span because we found no Karner blues on those surveys), a total of seven samples. We used paired *t*-tests because mean indices and CVs meet assumptions for parametric tests, and all data were from the same sites paired between different time periods.

(8) Comparison in trend: To test for trends in our and other datasets, we used Spearman rank correlation, both with the brood indices and a running average of these indices using three consecutive broods, in order to damp out short-term variability from fluctuations to make longer term trends more apparent. We sequentially numbered the broods (1 = spring 1990, 2 = summer 1990, 3 = spring 1991, and so on through 30 = summer 2004.), to enable trend analysis using both spring and summer broods. We re-ran these correlations using the Pearson product moment correlation on natural-log transformed indices, to test for differences between this linear test and the non-parametric Spearman rank correlation. We tested groups using both fewer sites to obtain longer time spans, and shorter spans to obtain larger samples of sites. We did these correlations using spring and summer indices, summer only, and spring only.

RESULTS

(1) Correlations within subregion among samples of sites: In central Wisconsin, all brood indices calculated from increasing samples of sites strongly covaried for the broods they had in common (using spring and summer indices, and summer only): 20/20 Spearman rank correlations were positively significant at $P < 0.05$, 18/20 at $P < 0.01$, and 13/20 at $P < 0.001$. The pattern was weaker but consistently positive in northwestern Wisconsin (summer indices only): $r = +0.855$, N = 10 broods, and $P < 0.01$ for 11- vs. 13-site indices; $r = +0.750$, N = 7 broods, near-significant at $P < 0.055$ for 13- vs. 15-site indices, but $r = +0.536$, N = 7, and not significant for 11- vs. 15-site indices. For Fort McCoy, the two-site and ten-site indices positively and significantly correlated ($P < 0.001$ for spring and summer; $P < 0.05$ for summer only).

The correlations among brood indices from different cohorts of monitoring sites (i.e., no overlap in sites among indices) were all positive but statistically weaker. In central Wisconsin (testing both spring and summer, and summer only), 9/12 Spearman rank correlations were significant at $P < 0.05$, 7/12 at $P < 0.01$, and 4/12 at $P < 0.001$. Again, the pattern was weaker in northwestern Wisconsin (summer only). The two Burnett County Forest sites and two Fish Lake Wildlife Area sites correlated significantly ($r = +0.929$, N = 7, $P < 0.01$) but the 11 Crex Meadows sites did not correlate ($P > 0.10$) with either Burnett County Forest or Fish Lake Wildlife Area sites. For Fort McCoy, the two-site and eight-site indices positively and significantly correlated ($P < 0.001$ for spring and summer; $P < 0.01$ for summer only).

(2) Comparisons of constant- and non-constant-site indices: For the non-constant-site monitoring in central Wisconsin, we calculated indices for 30 broods (mean 15.5 survey units per brood index, range 2-60); in northwestern Wisconsin (summer only), for 14 broods (mean 7.7 units/brood index, range 2-14). In central Wisconsin, non-constant-site brood indices correlated positively with constant-site indices (Fig. 3). These were significant at $P < 0.01$ when using spring and summer, both for N = 3 monitoring sites (summer 1990 on) and N = 5 monitoring sites (spring 1991 on); for summer only, $P < 0.05$ for the five-site correlation, and near-significant at $P < 0.10$ for the three-site correlation. In northwestern Wisconsin (summer only), the non-constant-site indices correlated positively with the 11-site indices at $P < 0.001$ (Fig. 4).

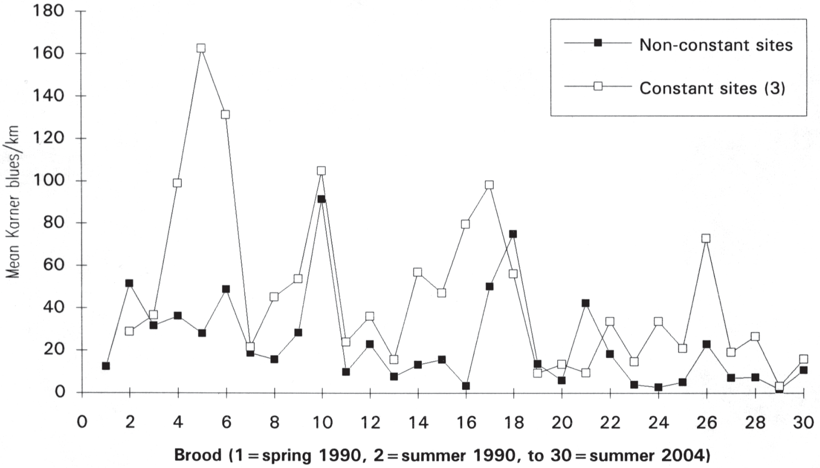

Figure 3. Mean Karner blues/km per brood for central Wisconsin, for constant-site and non-constant-site monitoring.

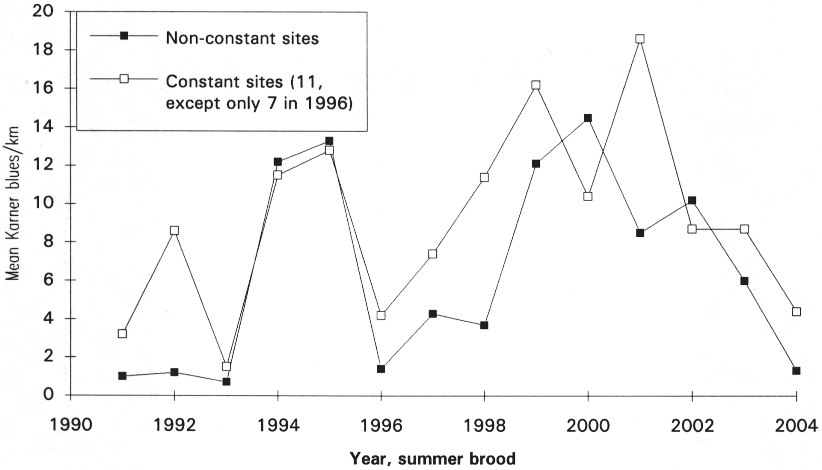

Figure 4. Mean Karner blues/km per brood for northwestern Wisconsin, for constant-site and non-constant-site monitoring.

(3) Comparison to other monitoring programs: In Spearman rank correlations of the HCP all-site index to all our constant-site and non-constant-site brood indices and to Fort McCoy indices, none (0/16) were significant. The HCP shifting mosaic (SM) index did not correlate significantly to our regional SM index, nor did the HCP permanency of habitat (PH) index with our regional PH index. Likewise, the Welch indices did not correlate significantly with our indices for Wood County (N = 2 sites), Jackson County (N = 3), or central Wisconsin (N = 5). Fort McCoy indices (N = 2 or 10 sites; spring and summer or summer only) also never correlated significantly with any non-constant-site indices (HCP or ours). However, Fort McCoy indices did have many significant correlations (all positive) with our constant-site indices (Table 2, Figs. 5-6). The ten-site Fort McCoy index produced similar or more significant *P* values than the two-site index. Fort McCoy indices did not correlate significantly with our northwestern Wisconsin index, but did with many indices from central Wisconsin, at both the county and subregion level, and with many of our whole-region indices.

(4) Comparison of additional survey(s) within brood: The lack of a third count did reduce the power of the correlation coefficient of the peak and second highest count in our dataset but both correlations were positive and significant ($r = +0.847$, N = 139 with third count; $r = +0.672$, N = 122 without; $P < 0.01$ for both). In the Fort McCoy surveys, the reduction in correlation when a third count was absent was so great as to become non-significant ($r = +0.943$, N = 119, $P < 0.01$ with third count; $r = +0.271$, N = 20, $P > 0.10$).

(5) Correlation among counties: Burnett County (northwestern Wisconsin) brood indices never correlated significantly with indices from central Wisconsin Counties: Jackson, Wood (Table 3) or Monroe (Fort McCoy, Table 2). Jackson and Wood County indices always correlated positively with each other, often significantly. The Monroe County indices correlated positively and often significantly with our Jackson and Wood County indices [see (3) above].

(6) Comparison of abundance by season: In central Wisconsin, where we have more years of spring data, the spring survey total averaged about two-thirds the summer total (Table 4). In comparisons controlling for which years are in the analysis (Table 4), more variation in this spring to summer proportion was apparent, with the spring total ranging from about half to equal the summer total. Some geographic variability was also apparent; sometimes but not always, nearer counties had nearer values. The sites and percents for Monroe County are nearer to Jackson than Wood County, Portage to Wood than Jackson County, and Burnett to Jackson than Wood County. Against this pattern, Jackson is geographically nearer to Wood than Burnett, and Wood is nearer to Jackson than Monroe or Burnett, but the percents did not ordinate accordingly. In Table 4, all our sites in all years possible, the mean spring index was significantly lower than the summer index (Mann-Whitney U test one-tailed $P = 0.0000$, N = 192 for each brood), with the mean spring index 70% of the summer (28.8 vs. 40.8 individuals/km). Eight (57%) of our 14 central Wisconsin sites had their highest population index ever in spring (2 in 1992, 5 in 1998, 1 in 2002); 6 (40%) of our 15 northwestern Wisconsin sites had their highest index ever in spring (5 in 1998, 1 in 1994), using data only from years when the sites were surveyed in both seasons. Four (40%) of the ten Fort McCoy sites had their highest index ever during 1999-2004 in spring (all in 2003). One Welch site had its highest index in spring (1991), the other in summer (1991).

(7) Variability among broods, a) short-term: For individual sites surveyed more than three years, spring broods had an average >4.5 factor difference (larger or smaller) from the previous summer, and summer broods >3.65 factor difference from the previous spring (not a significant difference vs. summer, $P > 0.3$ in all tests). For the same brood one year apart, spring averaged a >5.25 factor change and summer a >3.23 factor change. Spring broods varied significantly more than summer ($P < 0.05$) for central Wisconsin sites (8 sites 1992-2004 and

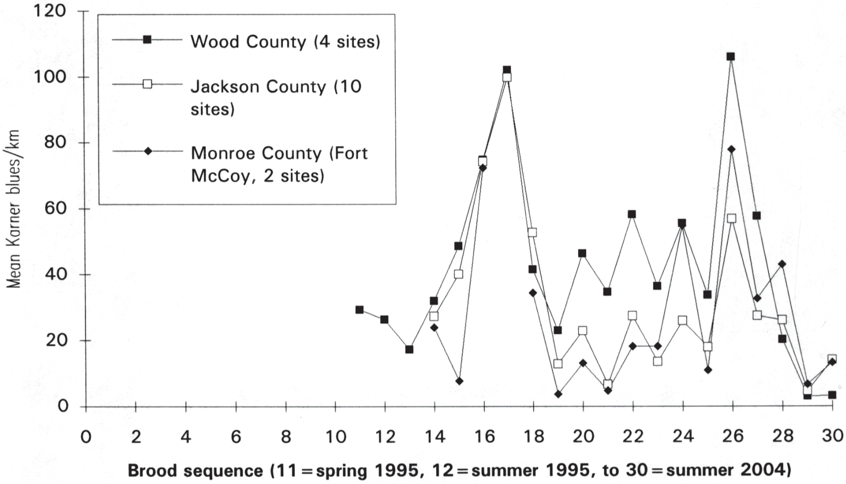

Figure 5. Mean Karner blues/km per spring and summer brood in the Swengel dataset (Wood and Jackson Counties) and the Fort McCoy dataset (Monroe County).

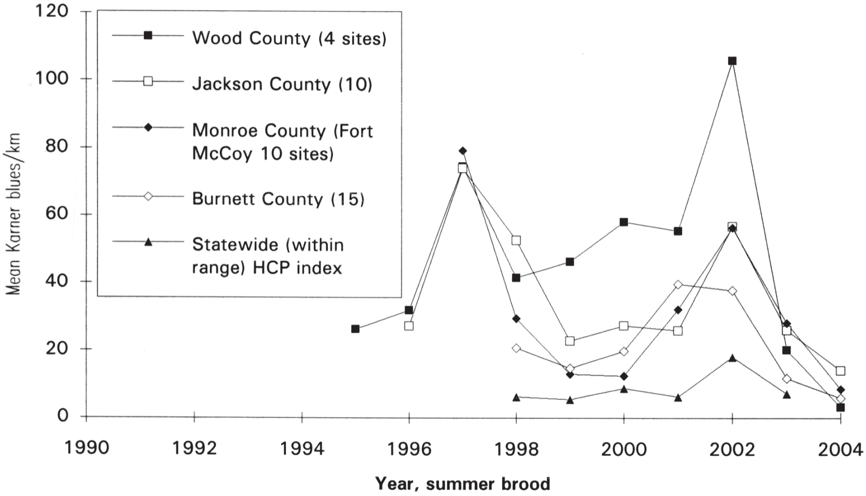

Figure 6. Mean Karner blues/km per summer brood in our dataset (Wood, Jackson, and Burnett Counties), the Fort McCoy dataset (Monroe County), and HCP dataset (statewide within range).

Table 3. Spearman rank correlation coefficients (r) of Karner blue indices per brood between sites grouped by county, for the broods and years data are available for both groups.

	Spring & summer			**Summer only**			**Spring only**		
	N	***r***	***P***	**N**	***r***	***P***	**N**	***r***	***P*** [1]
Burnett County[2] vs.:									
Jackson County[3]				14	-0.402	NS			
Jackson County[4]				13	-0.242	NS			
Wood County[5] vs.:									
Burnett County[2]				10	+0.139	NS			
Jackson County[4]	20	+0.629	<0.01	10	+0.406	NS	10	+0.685	<0.05
Jackson County[6]	17	+0.777	<0.01	9	+0.683	<0.05	8	+0.857	<0.01

[1] NS = $P \geq 0.05$ (all NS were $P > 0.10$)

[2] 11 sites, 1991 on; four sites lack a survey in summer 1996

[3] 3 sites, spring 1991 on

[4] 6 sites, spring 1992 on

[5] 4 sites, spring 1994 on

[6] 10 sites, spring 1996 on

Table 4. Mean of total Karner blue individuals on peak survey per site per brood on spring and summer broods in central Wisconsin (Jackson and Wood Counties), using data for each site for each year with both spring and summer values, for all sites during 1991-2004 and holding years of surveying constant within each group of comparisons.

	N sites	Spring mean ± SD	Spring CV	Summer mean±SD	Summer CV	N variates	Percent[1]
All sites and years possible							
Central Wisconsin	14	26.3 ± 48.1	182.6	38.5 ± 48.6	126.3	170	68.3
Jackson Co.	10	22.5 ± 51.1	227.1	35.4 ± 48.0	135.8	122	63.6
Wood Co.	4	36.1 ± 38.2	105.9	46.4 ± 49.6	107.0	48	77.8
1999-2004							
Central Wisconsin	14	12.6 ± 14.2	112.6	24.8 ± 34.6	139.1	84	50.8
Jackson Co.	10	9.0 ± 12.5	138.6	20.9 ± 33.2	159.0	60	43.1
Wood Co.	4	21.7 ± 14.5	66.9	34.8 ± 36.6	105.4	24	62.4
Fort (Monroe Co.)[2]	10	24.8 ± 40.3	162.3	49.2 ± 77.2	156.9	60	50.4
1991-1993							
Central Wisconsin	5	71.5 ± 121.7	170.3	103.6 ± 70.9	68.5	15	69.0
Jackson Co.	3	66.3 ± 148.7	224.1	117.0 ± 74.7	63.8	9	56.7
Wood Co.	2	79.2 ± 77.3	97.6	83.5 ± 66.0	79.0	6	94.9
Welch (Portage Co.)[2]	2	223.2 ± 123.6	55.4	196.3 ± 135.1	68.8	6	113.7
1994, 1998, 2004							
Central Wisconsin	10	42.7 ± 55.1	129.1	42.2 ± 59.1	140.0	30	101.2
Jackson Co.	8	39.9 ± 57.1	143.3	35.3 ± 48.4	137.0	24	113.0
Wood Co.	2	53.8 ± 48.9	90.9	69.7 ± 91.3	131.0	6	77.2
Burnett County	5	5.5 ± 7.5	137.2	5.6 ± 5.5	98.5	15	98.2

[1] Percent = spring mean/summer mean.

[2] Source for dataset provided in “Methods: Other monitoring datasets”.

14 sites 1996-2004), but not Fort McCoy (10 sites 1998-2004). The factor change between consecutive broods and same brood season in consecutive years (Table 5) tended to decrease as more sites were lumped, ranging from indices for individual sites to a single index combining all sites per brood. Indices pooling 10-14 sites varied 30% less between consecutive broods and 30-45% less for the same brood in consecutive years, than single-site indices. The statewide HCP summer brood index, with site selection changing each year, showed similar consecutive-year variation to our central Wisconsin and "statewide" indices using about half as many constantly monitored sites (Table 5).

7) Variability among broods, b) long-term: The mean CV for all population indices at all sites was 107.7 for spring (N = 24 sites), 94.7 for summer (N = 39), and 114.5 for both broods (N = 24). CVs of mean spring indices were significantly higher ($P < 0.05$) in denser Fort McCoy sites but not in other samples. CVs of mean summer indices were negatively related to population size in all tests (small sites varied more), significantly so ($P < 0.05$) only when central and northwestern Wisconsin sites were combined (N = 29 sites). In comparisons of CVs for shorter vs. longer periods in the 11 combinations of sites and broods, mean CVs for the entire period were typically 1.3 times larger than for the first half of the period (significantly so at $P < 0.05$ in 5/11 tests), and 1.1-1.15 times larger than for the second half (significantly so in 4/11 tests). This effect was more pronounced in the longer overall period analyzed (1992-2004): two-thirds of tests had significantly larger CVs for the entire period than for the first or second half of the period. Only 1/22 tests (the proportion expected due to chance) had greater variability in the first or second half than in the whole period. CVs for the second half were significantly greater than the first half 1/11 times, and never vice versa.

(8) Comparison in trend: For trend results with $P < 0.10$, the sign of the coefficient was always the same for a given group of sites, no matter the type of statistical test done (Spearman or Pearson correlation), the type of index used (running average or individual brood), or the set of seasons used (spring and/or summer) (Table 6). Constant- and non-constant-site brood indices for the same subregion in the same set of seasons (spring and/or summer) always had the same sign of coefficient and about the same proportion of significant trends (Table 6). Correlations using only summer indices or using both spring and summer indices produced about the same results with about the same level of significance. Correlations using only spring indices produced fewer significant results. Our smaller set of central Wisconsin sites for the longer period (eight sites for 24-26 broods) produced more significant results than comparable tests on the larger set of sites (14 sites for 15-18 broods).

Some near-significant positive trends occurred at Fort McCoy, central Wisconsin reserve (R), and northwestern Wisconsin (primarily R) sites. The dates selected for surveys in northwestern Wisconsin in summer 1995 and 1996 were rather early in the flight period (Fig. 2; Swengel and Swengel 1999). Recalculating these correlations to exclude 1995 and 1996 (for running averages, excluding 1995 and 1996 from calculation of running averages) does not change the significance or sign of coefficients in Table 6. R sites had non-significant or positive significant and near-significant results, except for one significant negative trend for the spring-only central Wisconsin eight-site index (Table 6, Fig. 7). In central Wisconsin, permanency of habitat (PH) and shifting mosaic (SM) sites had many negative (near-)significant trends, both for fewer sites over more years and more sites for fewer years (Table 6, Fig. 7). In northwestern Wisconsin, our very small sample of PH and SM sites (Table 1) was unanalyzable for trend. During our study, no canopy-clearing events occurred in our SM sites. Apart from routine mowing and brush-cutting in our PH sites, discrete events that exposed large areas of soil occurred in these central Wisconsin PH sites: Stanton Roadside (especially in 2000), Highway X north-south (2001-2004), Highway X east-west (2001), and Highway X south (1996, 2004).

Table 5. Mean factor change in brood indices for consecutive broods and for the same brood in consecutive years, by geographic scope (from individual sites to increasing lumping of sites).

	Factor change in consecutive broods[1]			**Factor change in same brood[1]**		
	summer to spring	**spring to summer**	**all broods**	**spring to spring**	**summer to summer**	**all broods**
Single sites						
Central (14 sites)	>3.65	>3.22	>3.06	>4.88	>3.24	>4.06
Jackson (10 sites)	>4.04	>3.52	>3.78	>6.68	>2.86	>4.77
Wood (4 sites)	>2.65	>2.46	>2.56	>3.41	4.18	>3.80
Burnett (13 sites)					>>3.47	
Fort (10 sites)[2]	>5.72	>4.24	>4.98	>5.78	2.89	>4.34
Multiple nearby sites						
2-4 sites (8 groups)	>2.81	>2.85	>2.83	>3.64	>2.34	>2.99
Jackson (6 groups)	>3.12	>3.06	>3.09	3.52	>2.32	>2.89
Wood (2 groups)	2.16	2.22	2.19	4.01	2.38	3.19
6-10 sites (2 groups) (Jackson County only)	2.80	2.37	2.58	3.15	1.77	2.46
Crex 2-4 (6 groups)					3.69	
Crex 5-7 (2 groups)					2.26	
County						
Jackson 10 sites (1 group)	2.98	2.47	2.73	3.40	1.77	2.48
Wood 4 sites (1 group)	2.09	1.98	2.03	3.58	2.38	2.98
Fort 2 sites (1 group)[2]	3.92	3.83	3.87	5.50	2.80	4.15
Fort 10 sites (1 group)[2]	3.01	2.73	2.87	3.08	2.37	2.72
Burnett 15 sites (1 group)					1.77	

Table 5. Continued.

	Factor change in consecutive broods[1]			Factor change in same brood[1]		
	summer to spring	spring to summer	all broods	spring to spring	summer to summer	all broods
Region						
14 sites (1 group)	2.54	2.19	2.36	3.23	1.78	2.51
State						
Swengel 1997-2004; 27-29 sites					1.73	
Swengel 1998-2004; 29 sites					1.80	
Swengel & Fort (Monroe)[2] 1997-2004; 37-39 sites					1.98	
Swengel & Fort (Monroe)[2] 1998-2004; 39 sites					1.97	
HCP (68.5 sites/yr)[2]					1.91	

[1] ">" indicates infinite ratio(s) were excluded from that calculation (see Methods).

[2] Source for dataset provided in "Methods: Other monitoring datasets".

Table 6. Karner blue population trend: Spearman rank correlation coefficients (*r*) of sequentially numbered broods (1 = spring 1990, 2 = summer 1990, etc.) with Karner blue indices calculated as three-brood running averages, for all broods available and for the same number of broods for each sample in the group (N = number of broods). Letters following *P* value represent results of three additional correlations: Spearman rank correlation not as a running average, and for Pearson's product moment correlation of natural-log transformed indices as running average, and not as running average, respectively.

	Spring & summer				**Summer only**				**Spring only**			
	N	***r***	***P*** ^{1}		**N**	***r***	***P*** ^{1}		**N**	***r***	***P*** ^{1}	
Central Wisconsin												
All (8 sites)	24	-0.608	<0.01	baa	11	-0.827	<0.01	bab	11	-0.582	<0.06	-bd
R^2 (2 sites)	24	-0.185	NS	—-	11	+0.464	NS	—-	11	-0.664	<0.05	-d-
PH^2 (3 sites)	26	-0.714	<0.001	aaa	12	-0.965	<0.001	aaa	12	-0.699	<0.05	bbb
	24	-0.677	<0.01	aaa	11	-0.964	<0.001	aaa	11	-0.718	<0.05	cbb
SM^2 (3 sites)	24	-0.790	<0.001	aab	11	-0.918	<0.01	aaa	11	-0.564	<0.10	-b-
Northwestern Wisconsin												
R^2 (11 sites)					12	+0.559	<0.06	-B-				
Modified fire^3					12	+0.762	<0.01	-A-				
Non-fire^3					12	+0.701	<0.01	-AD				
Central Wisconsin												
All (14 sites)	15	-0.589	<0.05	bbc	8	-0.381	NS	—-	6	-0.486	NS	—d
R^2 (4 sites)	18	+0.055	NS	—-	8	+0.667	<0.10	—-	8	-0.310	NS	—-
	15	-0.336	NS	—-	8	+0.667	<0.10	—-	6	-0.486	NS	—-
PH^2 (5 sites)	18	-0.236	NS	—-	8	-0.905	<0.01	-ad	8	-0.381	NS	—-
	15	-0.807	<0.01	baa	8	-0.905	<0.01	-ad	6	-0.771	<0.10	-bd
SM^2 (5 sites)	15	-0.636	<0.05	aaa	8	-0.810	<0.05	cac	6	-0.486	NS	-dd
Non-constant site												
Northwestern					12	+0.434	NS	—-				
Central	28	-0.669	<0.01	aaa	13	-0.802	<0.01	bab	13	-0.423	NS	bbb
					12	-0.762	<0.01	bad				
Combined	28	-0.744	<0.001	aaa	13	-0.753	<0.01	bab	13	-0.841	<0.01	aaa
					12	-0.699	<0.05	bad				

Table 6. Continued.

	Spring & summer				Summer only				Spring only			
	N	*r*	***P***[1]		N	*r*	***P***[1]		N	*r*	***P***[1]	
Central & Northwestern												
All (29 sites)					5	-0.100	NS	—-				
R[2] (17 sites)					5	+0.600	NS	—-				
PH[2] (6 sites)					8	-0.690	<0.10	-c-				
					5	-0.600	NS	—-				
SM[2] (6 sites)					8	-0.810	<0.05	-ad				
					5	-0.500	NS	—d				
Fort McCoy (Monroe Co.)[4]												
2 sites	12	+0.399	NS	-C-	7	+0.571	NS	—-	4	+0.800	NS	—-
10 sites	12	+0.429	NS	-C-	6	-0.028	NS	—-	4	+0.800	NS	-D-
All counties weighted equally in index[5]												
M-2[4]	11	+0.136	NS	—-	7	+0.143	NS	—-	4	+0.800	NS	—-
M-10[4]	11	+0.100	NS	—-	6	-0.143	NS	d-d	4	+0.800	NS	—-
with B, M-2[4]					7	+0.179	NS	—-				
with B, M-10[4]					6	-0.086	NS	—d				

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[1] NS = $P \geq 0.10$; A or a = $P < 0.01$, B or b = $P < 0.05$, C or c = $P < 0.06$, D or d = $P < 0.10$, - = $P \geq 0.10$; upper case is positive, lower case is negative.

[2] R = reserve; SM = shifting mosaic, PH = permanency of habitat.

[3] Modified fire management (10 sites); permanent non-fire refugium at Reed Corner (1 site).

[4] Source for dataset provided in “Methods: Other monitoring datasets”.

[5] Jackson and Wood Counties included in all indices; Monroe (M) County represented by either 2 sites (summer 1996 on) or 10 sites (summer 1997 on); when Burnett (B) County (summer only) is included, this is so noted.

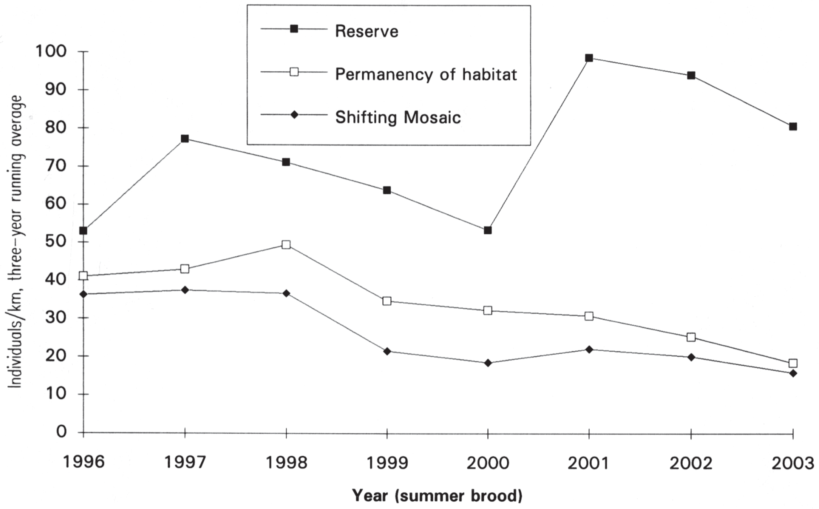

Figure 7. Mean Karner blues/km per summer brood, as three-year running averages, by management category in central Wisconsin.

In 1994, a permanent non-fire refugium was designated in Crex Meadows at Reed Corner, last burned in 1988. Elsewhere at Crex Meadows, individual burn areas have appeared to become smaller in many years (pers. obs.), and managers have mapped lupine and Karner blue occupancy to ensure that unburned, occupied lupine occurs near burned lupine (pers. comm. Paul Kooiker). Both the corner and non-corner constant-site indices show positive significant trends (Table 6). Early in our study, the corner index was lower than the mean index from non-corner constant sites, but this has consistently reversed for all years since (Fig. 8). Average time since last fire in our sample of non-corner constant sites, as a three-year running average, has mildly but non-significantly increased during our study (Spearman rank correlation $r = +0.238$, N = 12), but this is not apparent in non-running averages ($r = +0.097$, N = 14). Adding Reed Corner in this correlation, it is still not significant for mean year since last fire ($r = +0.418$, N = 14, $P > 0.10$), but as three-year running averages, it is ($r = +0.734$, N = 12, $P < 0.01$).

DISCUSSION

(1) Correlations within subregion among samples of sites: All correlations among brood indices from different pools of sites in the same subregion were positive, and significance occurred in 22/24 tests. The stricter test to correlate indices from different cohorts of monitoring sites (i.e., no overlap in sites among indices) was weaker, but positive significant correlations still occurred at a rate (69%) much higher than the expected (random) 5%. Thus, results would appear adequately similar in these datasets, whether the indices are from fewer sites with more years of data or from more sites with fewer years of data.

(2) Comparisons of constant- and non-constant-site indices: The non-constant-site brood indices performed remarkably similarly to constant-site indices (Figs. 3-4). The less restrictive characteristics of our non-constant-site indices (wider span of survey timing within brood; changing sample of sites) should serve to confound correlation, but in all instances the correlation was positive and in most instances significant.

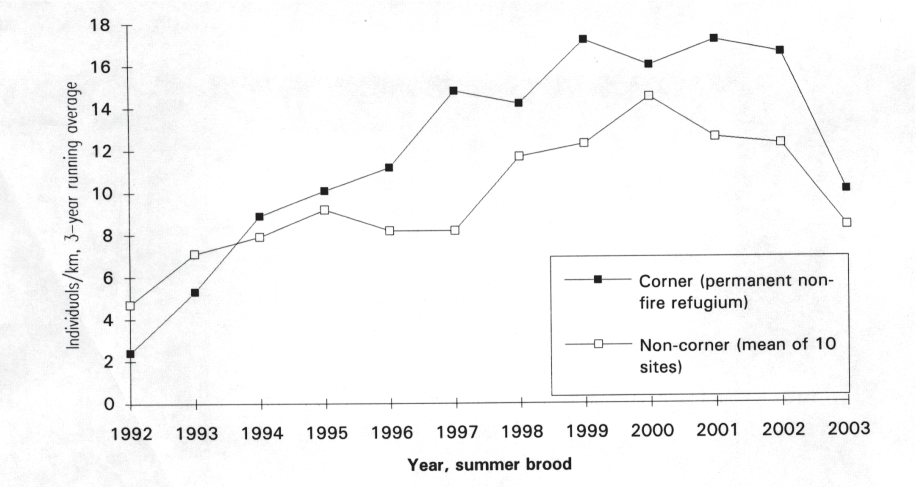

Figure 8. Mean Karner blues/km per summer brood, as three-year running averages, at Reed Corner (permanent non-fire refugium) and ten sites (non-corner) in modified fire management at Crex Meadows.

(3) Comparison to other monitoring programs: The HCP index, which had no significant correlations with any index tested here, had several risk factors disfavoring correlation (small sample of broods, changing sample of sites). Likewise, our non-constant-site indices, despite the large number of broods, never had significant correlations with constant-site indices from other monitoring programs [but did with our constant-site indices, see (2) above]. The Welch dataset, which also had no significant correlations, had two risk factors as well (few sites, few broods). However, some correspondence is apparent between the Welch indices and our central Wisconsin constant-site indices (Swengel and Swengel 1996: Fig. 2), and between the HCP index and other indices (Fig. 6), especially in the direction of change between consecutive broods.

Fort McCoy constant-site indices had relatively many significant correlations with our constant-site indices (Table 2), biased toward our indices from nearer sites (i.e., partially or entirely from central Wisconsin). Since the ten-site Fort McCoy index produced more significant correlations than the two-site index, the addition of eight sites appeared more valuable statistically than the increase of two broods (one spring, one summer). Correlations using both spring and summer broods produced more significant correlations than the same correlations using only spring or summer broods. Thus, monitoring in both spring and summer appears to produce more statistical power sooner (in terms of years of surveying) than monitoring one brood per year, although it is unclear whether spring results add more amplitude to the variation, or simply add sample size.

Constant-site indices (ours and Fort McCoy's) had a much stronger statistical relationship with each other [Table 2; also (5) below] than with non-constant-site indices (ours and HCP's) or between non-constant-site indices. This indicates that constant-site monitoring is more powerful statistically than non-constant-site monitoring. Non-constant-site programs may arise from two sources: a less rigorous, likely volunteer program such as the NABA-Xerces Butterfly Count (Swengel 1990) or from an attempt, as in the HCP, to address site turnover due to forest succession. In the latter case, it appears more useful, instead, to keep sites constant by selecting them from all successional stages. Once a site loses its Karner blues due to succession, they can be assumed, for the sake of efficiency, to remain absent without further surveying until a canopy-reducing event (wildfire, tree-cutting) would require surveys to resume. Alternatively, one cohort of sites could be surveyed for a period of time (e.g., a decade), then a new cohort started, ideally with overlap in surveying the old and new cohorts, to calibrate the relationship of the data from each cohort. This keeps sites constant for an extensive period, but allows the opportunity to change sites. Monitoring programs become disproportionately more valuable the longer they exist, and are more powerful when the sample of sites is large, constant, and representative of a broad spectrum of canopy cover and land uses (Conrad et al. 2004).

(4) Comparison of additional survey(s) within brood: When a third count was available for a particular site in a brood, the correlation of the peak and second highest counts was stronger and always significant. This suggests that repeated surveying produces two counts that approximate each other more, presumably because they are both closer to peak. The absence of a third count appeared more disadvantageous in the Fort McCoy dataset than ours. Most sites at Fort McCoy had three or more surveys in most broods, so that the sample of sites without a third count was small. The goals of our survey timing may be different as well. In ours, we aim for a single peak count, and so are willing to space our (fewer) surveys at less than one-week intervals. The Fort McCoy dataset appears to aim for counts spaced not much less than a week apart, to cover the entire flight period more systematically. In that case, it is more important to do more surveys per site per brood, as has been done at Fort McCoy.

(5) Correlation among counties: The results from correlations of brood indices by county within our dataset and between ours and Fort McCoy's (Monroe County) indicate that synchronization of abundance fluctuations and trends occur at a scale larger than these counties (Tables 2, 3), since the indices from the three central Wisconsin counties (Jackson, Monroe, Wood) correlated positively and often significantly. This synchronization weakens between subregions, as the central Wisconsin county indices from the different subregions never correlated significantly with indices from Burnett County (northwestern Wisconsin), ca. 220-265 km away.

Our correlations are a stringent test, as they are ranking the relative abundance of the brood indices, not just whether they are rising and falling similarly. Lack of significant correlation in our tests does not mean there isn't still meaningful correspondence as to when brood indices rise or fall markedly. Swengel and Swengel (2005) also analyzed for synchrony of fluctuations but in that analysis, the population indices were detrended to remove the effects of any upward or downward trend (significant or not) before analysis. In that paper, positive correlation occurred across our entire study region. As here, the correlation was greater for closer sites than more distant ones. In this paper, the use of "trended" data had the effect of increasing the positive correlation of near sites and decreasing the correlation of further sites (which tended to have opposite trends).

Synchrony, or spatial autocorrelation, of butterfly populations within a region is a widespread phenomenon (Pollard 1991). As with Karner blues in Wisconsin, many other butterfly population changes correlate better among nearer sites than more distant ones (Ehrlich et al. 1980, Sutcliffe et al. 1996). Schultz and Hammond (2003), however, did not find spatial autocorrelation in long-term monitoring of an endangered blue in four counties in the Willamette Valley, Oregon, USA.

(6) Comparison of abundance by season: The relationship of the population indices from spring to summer varied greatly among years, with the spring index about 50-100% as large as the summer index, but the long-term average about two-thirds the summer brood in our dataset (i.e., summer averages a 50% increase from spring) (Table 4). In the Fort McCoy dataset, the spring index averages about 50% the summer index (i.e., summer averages a

100% increase from spring) (Table 4). While over the long-term, spring indices are significantly smaller than summer indices, the spring brood index is sometimes higher than the following summer's (Fig. 5: spring 1995, 1998, 2003). Furthermore, variability due to season (spring vs. summer) is relatively small compared to variability due to fluctuation. Long-term average fluctuations from spring to spring broods and summer to summer broods range from 241% to 568% (after converting factor-fold figures in Table 5 to percent changes).

(7) Variability among broods, a) short-term: Population size varied more in spring than summer and the larger the geographic scale of an index, the lower the variability. Thus, this variability should confound analyses more at smaller than larger geographic scales. Summer brood variation in the statewide HCP indices was consistent with our findings. Two studies of about three years found Karner blue fluctuations similar to ours. Lane and Andow (2003) found 2-10 factor differences in single-site adult population indices between most consecutive broods in east-central Wisconsin, while Kwilosz and Knutson (1999) had on average 2-2.5 fold changes between consecutive broods and the same brood in consecutive years. In Britain, indices for multiple-brooded butterflies usually vary more than for single-brooded ones, with the Karner blue's variability at the upper range found in Pollard and Yates (1993). In ten years of transect counts of a single-brooded blue, annual indices varied by an average 2.35 factor in consecutive years at individual sites and by 1.48 for the five sites combined (Mattoni et al. 2001): 20-30% less variability than we found for the spring brood and 50-60% less than/ the summer brood, but following our pattern of reduction with increasing geographic scale.

7) Variability among broods, b) long-term: CVs of mean Karner blue indices estimate long-term population variation. These CVs varied more in spring than summer, but both broods had large CVs—about 100% of the mean. Since both fluctuations and trends in abundance would affect the CV, it would be expected to increase with greater time. Consistent with that, the longer the period sampled (1992-2004 vs. 1998-2004), the larger the gap in CVs between the entire period and its halves. Karner blues exhibited slightly more long-term variation than a single-brooded blue in a 10-year study (Schultz and Hammond 2003). The inability of short monitoring periods to predict long-term population dynamics of blues can be extreme (Thomas et al. 2002). Thus, longer monitoring programs (>10 years) are necessary to characterize fully their population dynamics. As found here, CVs in British butterfly annual indices decline greatly going from the scale of unit to combined averages of a site (25-60% decrease), region (100 km radius; 30-70%), and nationwide (50-75%) (Sutcliffe et al. 1996).

(8) Comparison in trend: When correlations using indices from spring only and from larger sets of sites with fewer years produced fewer significant results (Table 6), it is not possible to distinguish whether spring broods and the larger sets of sites have no trend, or these correlations are too weak statistically. It is also difficult to assess whether significant trends indicate fairly long-term fluctuations in response to long-term climatic oscillations.

To try to distinguish climatic influences affecting all sites in an area from other factors affecting only certain sites, we subdivided sites by management class used in the HCP (Table 6). Our sample of sites and years for all three categories was analyzable only in central Wisconsin. Our reserve (R) sites had the most favorable results: almost always positive, sometimes (near-) significant. This is heartening, since R sites are where most changes have been made to habitat management to favor Karner blues. Significant declines in our shifting mosaic (SM) sites are unsurprising, since these timber management sites had no tree-cutting during our study. Thus, canopy would be expected to be increasing in these sites, and Karner blue abundance is negatively related to forest canopy (Swengel and Swengel 1996, Grundel et al. 1998).

Significant declines in permanency of habitat (PH) sites (rights-of-way) are more concerning, as these sites are intended to maintain Karner blues consistently. Routine managements there (mowing/brush-cutting once per year or less) have been found favorable for Karner blues (Schweitzer 1994, Smallidge et al. 1996, Swengel and Swengel 1996, U.S. Fish and Wildlife Service 2003). Most of these sites, however, experienced soil-exposing events, outside the management guidelines of the HCP (Wisconsin Department of Natural Resources 2000), that destroyed vegetation. Thus, these other events are implicated in the declines. It is laudable for the HCP to try to regulate right-of-way management, where Karner blues and other butterflies, such as the state-listed Frosted Elfin (*Callophrys irus* (Godart), Lepidoptera: Lycaenidae), occur (Bureau of Endangered Resources 1999, Swengel 1996). Rights-of-way are managed by a diversity of agencies for purposes other than nature conservation. Attitudes of the public, including landowners bordering rights-of-way, regarding acceptable land uses in rights-of way (e.g., bare-soil tracks by all-terrain vehicle use), can also be important influences on right-of-way management, which appear difficult to change. Thus, it is much more important that positive results are occurring in R sites than that negative results are occurring in PH sites; the reverse would be much more alarming.

At Crex Meadows, the index from the permanent non-fire refugium (Reed Corner) appeared to outperform the non-corner sites, which continued in fire management with modifications (Fig. 8). Both the corner and non-corner sites have similar positive trends (Table 6), and favorable alterations to management have occurred not just at the corner but also at the other sites, where burn size has been reduced and recolonization facilitated by increased proximity of unburned occupied lupine to burned lupines. Since we lack adequate data to test for trends in PH and SM sites in that subregion, it is not possible to determine how much the positive trend in R sites at Crex Meadows is due to climate or to management modification.

Nonetheless, positive trends at Crex Meadows are consistent with previous studies that Karner blues are relatively more tolerant of fire management than other specialist butterflies, but can still be negatively affected by it (Schweitzer 1994; Swengel 1994, 1995; U.S. Fish and Wildlife Service 2003). Other studies of specialist butterflies have advocated patchy fires that leave unburned refugia both within the burn perimeter and nearby (Panzer 2002, 2003), with an emphasis on refugia in the densest part of the butterfly population (Schweitzer 1994, New et al. 2000). At Indiana Dunes National Lakeshore, an unburned high-quality Karner blue refugium within a burn unit had 50% as many Karner blues as adjacent sections of the unit before burning but 200% as many after the burn (Kwilosz and Knutson 1999: 103), a four-fold better trend for the refugium than burned areas. A fire refugium increases in value to specialized forest insects the longer it exists and its effects are not duplicated by haphazardly placed clear-cut refugia (Gandhi et al. 2001, Gandhi et al. 2003).

CONCLUSION

A favorable trend due to climatic fluctuation could mask effects due to unfavorable changes in site vegetation and/or management, while an unfavorable trend due to climatic fluctuation could mask favorable changes in site vegetation and/or management. Thus, it is essential to distinguish the underlying factors associated with trends, to avoid taking inappropriate actions relative to site vegetation and/or management. It seems likely that local factors (e.g., more favorable recent management at Crex Meadows and unfavorable soil-exposing events in several central Wisconsin rights-of-way, discussed above) are partly responsible for the different population trends in our central and northwestern Wisconsin sites, since their climates are not very different.

Our sample of sites, and counties, is relatively small compared to the extent of Karner blue occurrence in Wisconsin (Wisconsin Department of Natural Resources 2000). None of the sites in our constant-site monitoring became extirpated, although several shifting mosaic and permanency of habitat sites had some indices of zero and became small by the end of the study. Because nearly all of these sites are near other Karner occurrences, their chances of extirpation are smaller than in isolated populations. Furthermore, relatively little information is available about the status and trend of this butterfly in the state from before our study, so that it is not possible to put our results into a longer-term context. It is inappropriate to use our monitoring results to make general conclusions about the status and trend of this butterfly in Wisconsin. Although we obtained significance at a rate far higher than the random, 5% due to Type I error, an individual result can nonetheless be a Type I error. Greater confidence should be placed in patterns that recurred frequently with strong significance (or consistent non-significance). Our data are most useful for demonstrating the large variability possible in monitoring datasets, and differential fluctuations and trends among regions and types of sites.

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