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RANGEWIDE TRENDS IN LANDUSE AND NORTHERN BOBWHITE ABUNDANCE: AN EXPLORATORY ANALYSIS

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ABSTRACT

Biologists generally assume that habitat loss, fragmentation, and conversion resulting from changes in landuse are primarily responsible for the nearly rangewide declines in northern bobwhite (*Colinus virginianus*) abundance noted since at least 1990. Few data-based analyses have addressed this relationship at broad spatial scales. We used data on northern bobwhite abundance from the North American Breeding Bird Survey (BBS; 1966–1999) and county-level landuse from the U.S. Census of Agriculture (COA; 1978, 1987, 1997) to evaluate how 9 landuse variables related to northern bobwhite abundance at the rangewide spatial scale. We also explored the relationship between cropland cover and northern bobwhite abundance by state, physiographic region, and using a moving window approach. Although northern bobwhite abundance typically decreased at the rangewide spatial scale, trends in abundance varied considerably spatially, either exhibiting no trend or increasing in many western and northern portions of this species' range. While both spatial and temporal patterns in landuse were obvious, there were no clear univariate or multivariate relationships among these variables and bobwhite abundance that could be applied universally across this species' range. The relationship between cropland cover and northern bobwhite abundance based on physiographic regions was more interpretable than that based on political boundaries (states). When data were used to define spatial patterns between cropland cover and northern bobwhite abundance, spatially consistent and temporally persistent patterns were obtained. We suggest that further research using moving windows of various dimensions, including landuse variables in addition to cropland, and adding several more decades of bobwhite and landuse data is an essential aspect of formulating defensible, spatially explicit strategies for northern bobwhite conservation and management.

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Key words: abundance, *Colinus virginianus*, habitat, landscape, landuse, northern bobwhite, spatial scale, trends

INTRODUCTION

During the last few years, most authors of scientific articles addressing northern bobwhite biology attempted to justify their research by citing articles published since 1990 that quantified long-term, broad scale declines in northern bobwhite abundance. These studies relied primarily on either Christmas Bird Count (Brennan 1991) or BBS data (Droege and Sauer 1990, Church et al. 1993, Brady et al. 1998). Three issues are important for conceptualizing the current concern with declines in northern bobwhite abundance. First, eminent quail biologists have lamented long-term, broad-scale declines in northern bobwhite abundance for at least 70 years. For example, Leopold (1931:26), Errington and Hamerstrom (1936:382), and Lehmann (1937:8) all argued that state- and subcontinent-wide declines in bobwhite abundance began somewhere between 1875 and 1905. Similarly, Stoddard (1931:xxi) justified his mammoth study of northern bobwhites because “difficulty is now being experienced in maintaining these birds in numbers in many parts of their

range.” Probably the only substantive difference between historical and recent concerns regarding the demise of the northern bobwhite is that studies published since 1990 are better quantified. Second, apparently many authors assume, since northern bobwhite abundance is declining in numerous areas, that any and all bobwhite data are now more critically needed than previously—even if these data have little if anything to do with population dynamics or trends in abundance. Lastly, it is generally assumed that habitat loss, fragmentation, and conversion resulting from changes in landuse are primarily responsible for declines in northern bobwhite abundance (Brennan 1991, 1993; Church and Taylor 1992, Brady et al. 1998). Unfortunately, although hundreds of articles have evaluated how northern bobwhites use habitat at the scale of pastures, few data-based analyses have addressed how trends in bobwhite abundance vary with changes in landuse and landcover (Lee and Brennan 1994), particularly at the physiographic region to rangewide spatial scales.

Brady et al. (1993) attempted to address part of this deficiency by identifying landuse characteristics

Table 1. Correlations between northern bobwhite abundance (5-year means centered on 1978, 1987, and 1997) from North American Breeding bird survey data (Sauer et al. 2000) and landuse variables^a from the Census of Agriculture (USDA-NASS 2000) calculated using 100,000 randomly selected points from the interpolated surfaces.

	1978		1987		1997	
	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>
Average farm size	0.05838	<0.0001	0.15105	<0.0001	-0.03639	<0.001
Cropland cover	-0.21904	<0.0001	-0.06675	<0.0001	0.19904	<0.001
Rangeland cover	0.20916	<0.0001	0.36566	<0.0001	0.29108	<0.001
Woodland cover	0.12962	<0.0001	-0.01635	<0.0001	-0.13722	<0.001
CRP/WRP land cover			0.07212	<0.0001	0.28441	<0.001
Positive crop cover ^b	0.01316	0.8811	0.09435	<0.0001	0.40259	<0.001
Negative crop cover ^c	-0.33351	<0.0001	-0.19062	<0.0001	-0.03969	<0.001
Other crop cover ^d	-0.07499	<0.0001	-0.06994	<0.0001	-0.00608	0.0607
Cotton cover	0.21202	<0.0001	0.28432	<0.0001	0.13466	<0.001

^a All landuse variables are percent cover, except average farm size.

^b Sorghum, rice, wheat, oats, barley (5 items).

^c Cotton, hay-alfalfa, corn for grain or seed, corn for silage or green chop (4 items).

^d Sunflower seed, soybeans, peanuts, dry edible beans, tobacco, potatoes, sugar beets, sugar cane, pineapples, vegetables, and land in orchards (11 items).

correlated with differing northern bobwhite abundances at the statewide spatial scale in Kansas. They used data from the U.S. Department of Agriculture's COA and National Resources Inventory for Kansas counties where bobwhites were counted during a single rural mail carrier survey conducted in 1982, and BBS data for 1974, 1978, 1982, and 1987. Because there was no long-term trend in bobwhite abundance between 1967 and 1988 in Kansas, the authors could not address how changes in landuse might influence long-term trends in quail abundance. Similarly, they found no correlation between short-term trends in agricultural landuse and northern bobwhite abundance between 1974 and 1987. They did, however, delineate several landuse characteristics associated with the presence and absence of northern bobwhites and relative bobwhite density. Similarly, Roseberry and Sudkamp (1998) used classified satellite imagery (1991–95), county-level bobwhite harvest (1989–93), and BBS (1993–96) data to assess landscape suitability for northern bobwhites in Illinois. Their model was able to identify and map landscapes that were potentially suitable for bobwhites. Again, they did not address how long-term changes in landscape characteristics might influence trends in bobwhite abundance.

In an attempt to explain how northern bobwhite abundance varied by landuse at the rangewide spatial scale, as well as explore possible explanations for long-term trends in bobwhite abundance, Brady et al. (1998) used northern bobwhite abundance data from the BBS (1970–94) and landuse data from the National Resources Inventory (1972, 1982, 1992). The landuse data were evaluated at 2 spatial scales within a nested hierarchy: 10 Land Resource Regions and 86, multi-county Major Land Resource Areas (10,000–285,000 ha). Using correlative approaches, they found that for any given year, bobwhite abundance was positively associated with the percent of rangeland and certain crops, while negatively associated with percent land in urban areas, forest, and certain other crops. When bobwhite abundance among years for given physiographic regions was considered, 10 landuse and 6 spatial variables were correlated with trends in northern bob-

white abundance. Interestingly, the models could account for only 35 to 52% of the spatial and temporal variation in bobwhite abundance.

Although Brady et al. (1993), Roseberry and Sudkamp (1998), and Brady et al. (1998) all demonstrated that landuse and landscape characteristics were associated with the relative abundance of northern bobwhites at broad spatial scales, only Brady et al. (1998) attempted to address how changes in landscapes might be associated with long-term trends in northern bobwhite abundance. They suggested that, because their models accounted for only a limited amount of the variation in bobwhite abundance among years, that more detailed analyses, possibly relying on vegetative composition or successional stage, might be warranted. An alternative approach relates to the spatial scale at which data were collected. Because the landuse data utilized by Brady et al. (1998), for example, were collected at much broader spatial scales than were the bobwhite data, it is possible that considerable landuse information was lost that could help one better understand trends in northern bobwhite abundance. Similarly, because National Resources Inventory data were available for only 1982, 1987, and 1992, the timeframe addressed was rather limited.

In this exploratory analysis, we used northern bobwhite abundance data from the BBS (Sauer et al. 2000) and county-level landuse data from the United States Department of Agriculture's COA (USDA-NASS 2000) for 1978, 1987, and 1997 to better elucidate how changes in landuse are related to long-term trends in northern bobwhite abundance at the rangewide spatial scale in the United States. Additionally, we evaluated the relationship between cropland cover and northern bobwhite abundance by state, physiographic region, and using a moving window approach to illustrate how more detailed, spatially explicit analyses could help us better understand trends in bobwhite abundance.

METHODS

Databases and Data Preparation

Northern bobwhite abundance data were obtained from the BBS (Sauer et al. 2000) and used to develop

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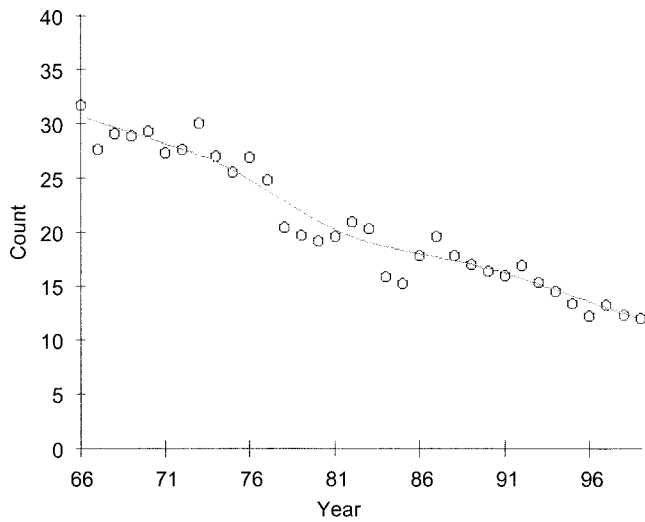


Fig. 1. Rangewide trend in northern bobwhite abundance based on North American Breeding Bird Survey data, 1966–1999 (Sauer et al. 2000).

interpolated abundance maps over northern bobwhite range for 1978, 1987, and 1997. These years were chosen because COA (USDA-NASS 2000) landuse data were available for these years. Given the high temporal variability of northern bobwhite abundance and because we were interested in long-term trends in abundance, a 5-year mean value centered on each of these years was generated for all routes surveyed in ≥ 3 of

the 5 years. These route data then were used to generate ArcView grids of the northern bobwhite abundance (2×2 -km² resolution) using the first power inverse distance weighted (IDW) interpolation method in ArcView Spatial Analyst (ESRI 1998).

County-level landuse statistics were extracted from the Censuses of Agriculture (USDA-NASS 2000) taken in 1978, 1987, and 1997 for cropland, rangeland, woodland, and CRP/WRP cover, as well as average farm size. These years were chosen for this exploratory analysis because previous censuses were not available electronically. These variables were interpolated over northern bobwhite range to generate 2×2 -km² grids using the same method described above.

Because, as expected, there was a high degree of spatial autocorrelation among values in the interpolated grids, 100,000 grid cells were randomly selected within northern bobwhite range and used to generate new grids for each of the abundance and landuse variables. The spatial autocorrelation, as measured by Moran's I, decreased from ~ 1 (near perfect positive autocorrelation) to ~ 0.1 (little autocorrelation) for the sampled grids containing only those 100,000 cells. These randomly sampled grids were used for all subsequent analyses.

Analyses

To explore the relationships among northern bobwhite abundance and individual landuse variables, we

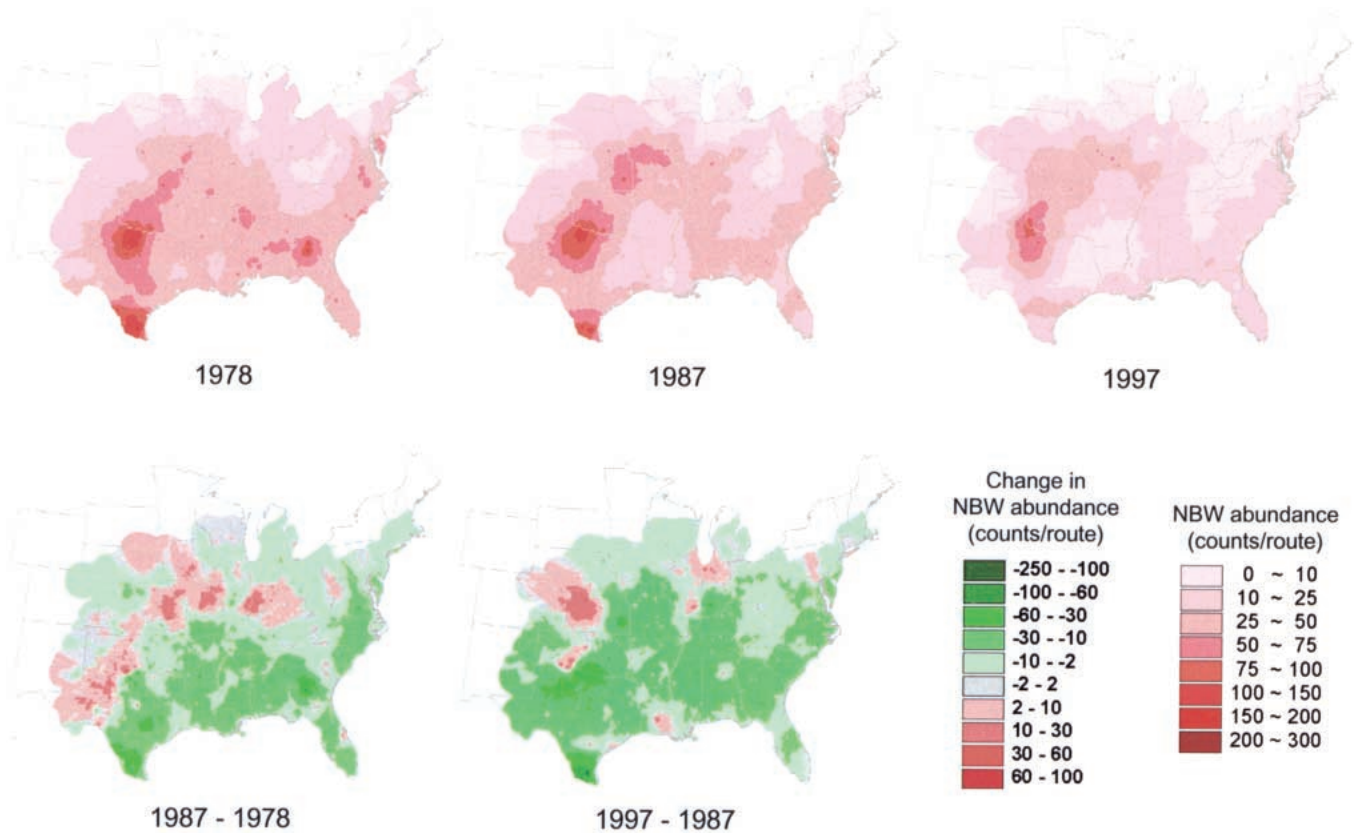


Fig. 2. Interpolated northern bobwhite population index based on the 5-year mean from the North American Breeding Bird Survey (Sauer et al. 2000) centered around (A) 1978, (B) 1987, and (C) 1997, and its changes from (D) 1978 to 1987, and (E) 1987 to 1997.

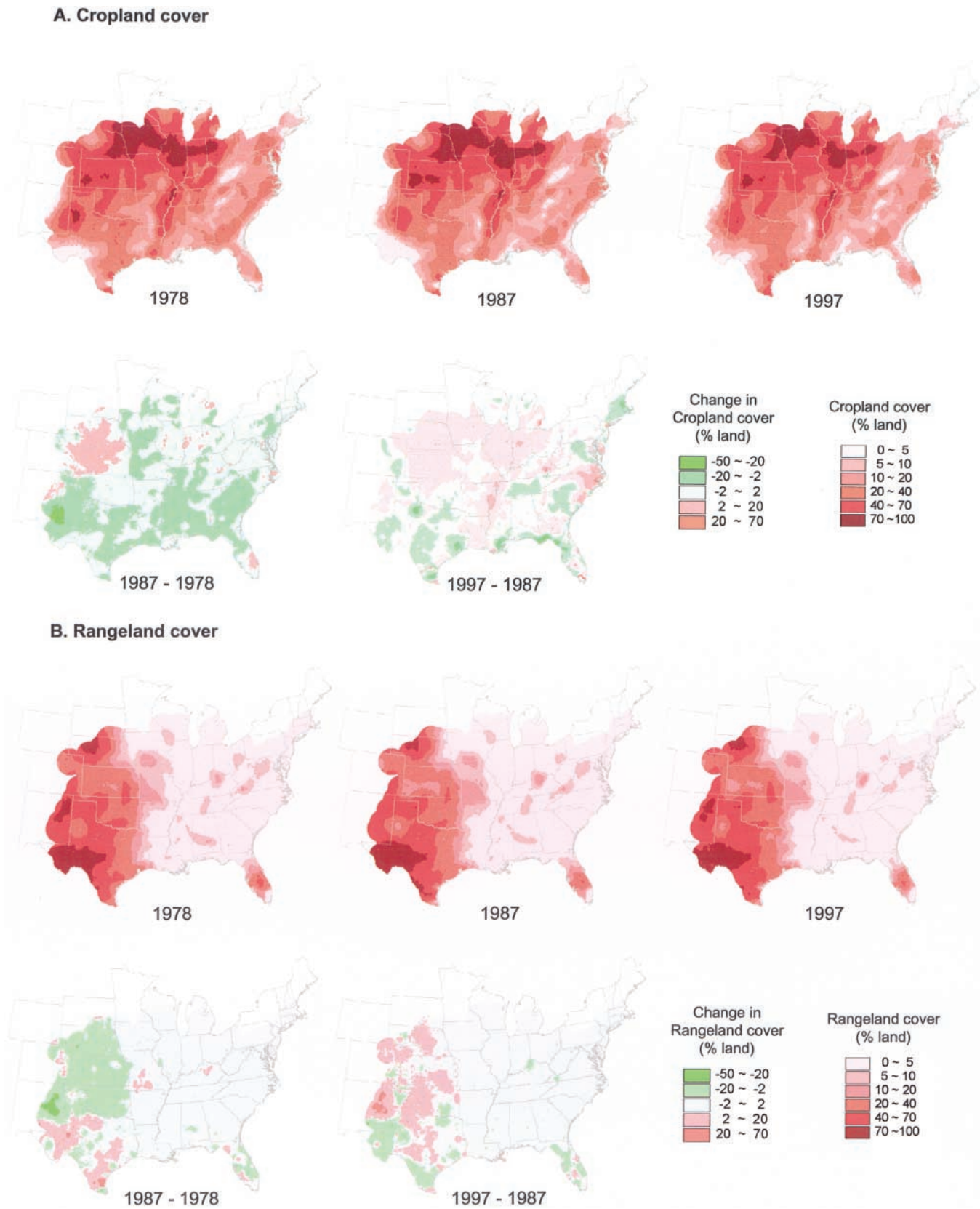
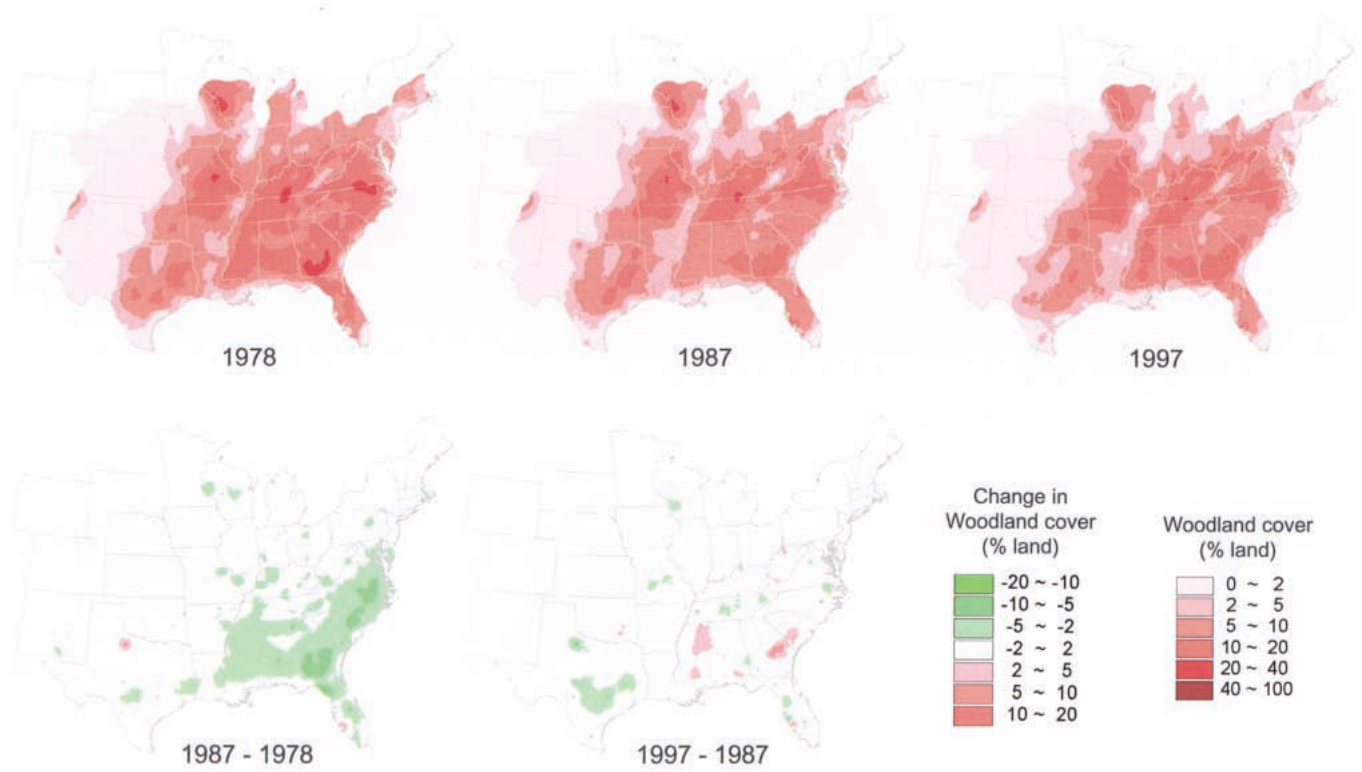


Fig. 3. Spatial interpolations of (A) cropland, (B) rangeland, (C) woodland, and (D) CRP/WRP cover, as well as (E) mean farm size in 1978, 1987, and 1997 within the northern bobwhite range based on county-level data from the Census of Agriculture (USDA-NASS 2000).

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C. Woodland cover



D. CRP/WRP cover

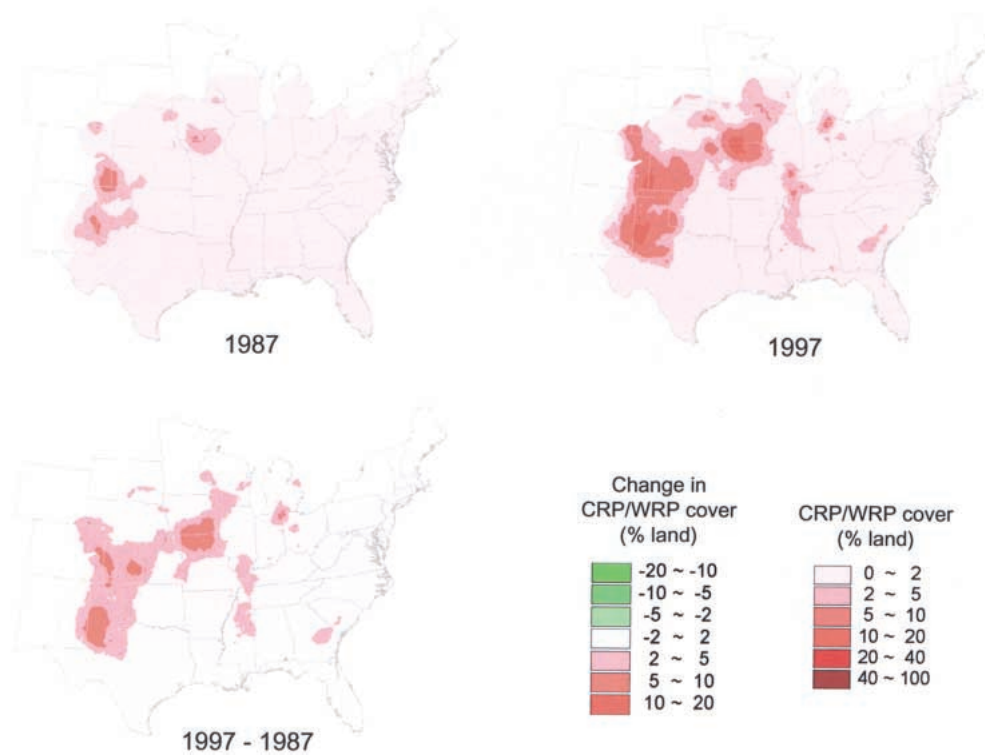


Fig. 3. Continued.

E. Average Farm Size

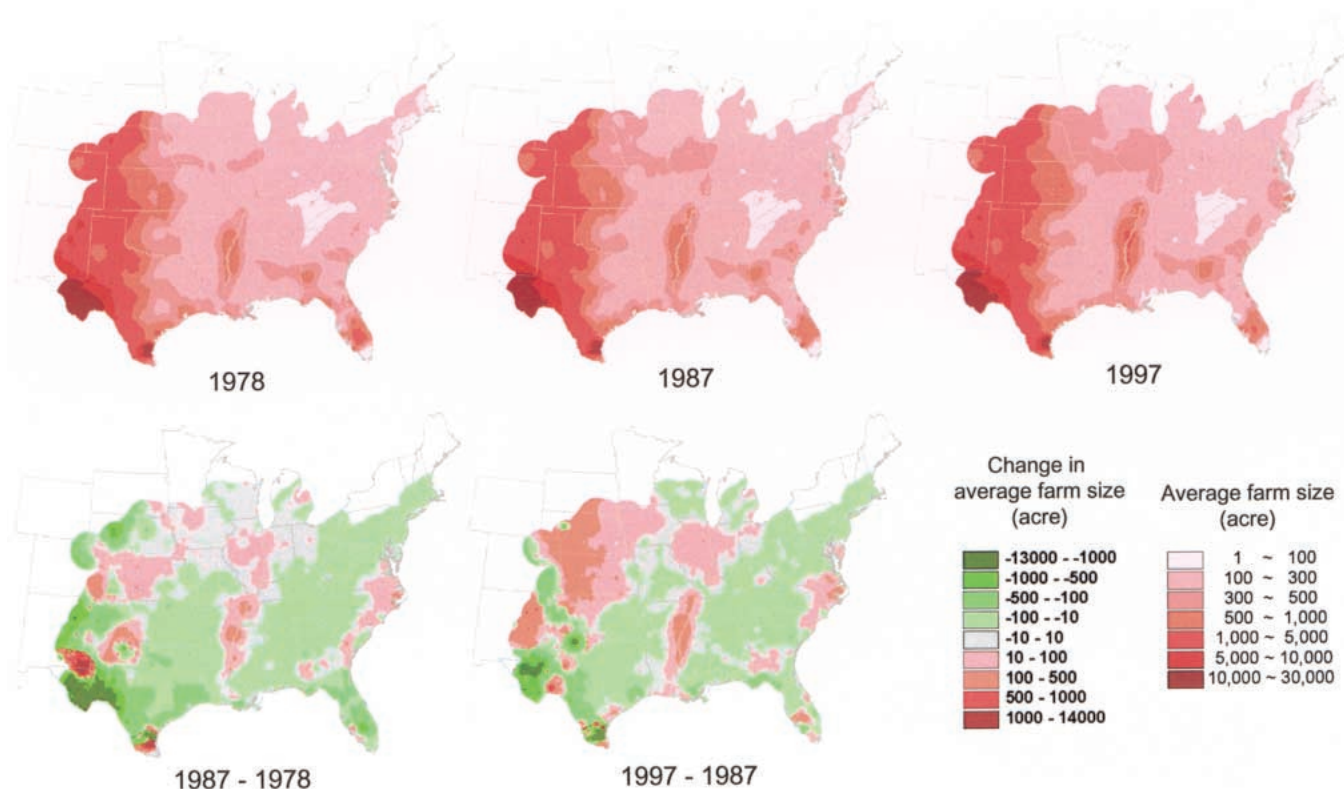


Fig. 3. Continued.

calculated Pearson's correlation coefficients (SAS Institute 1989) between northern bobwhite abundance and each landuse variable listed earlier for 1978, 1987 and 1997 using the randomly sampled grids. We also categorized crops as positive, negative, other, and cotton, based on how these crops commonly are perceived by quail biologists (see Table 1 for definitions). Because it is possible that relationships among landuse variables and northern bobwhite abundance are multivariate or additive rather than univariate, we used multivariate approaches to screen for possible multivariate effects of landuse on northern bobwhite abundance. First, we regressed northern bobwhite abundance against the landuse variables using stepwise regression (SAS Institute 1989). We also conducted principal factor analysis for the landuse variables, and then regressed northern bobwhite abundance against the factor scores we obtained (SAS Institute 1989).

Because spatial/regional variations in the northern bobwhite-landuse relationship might prevent crisp, rangewide relationships between northern bobwhite abundance and landuse, we also evaluated the relationship between northern bobwhite abundance and cropland cover in 1978, 1987, and 1997 by state, physiographic region, and using a moving window approach as examples of how more detailed, spatially explicit analyses might clarify these relationships. It was beyond the scope of this study to evaluate numerous landuse variables. Cropland cover was chosen for this exercise because it generally is thought to be

critically important to northern bobwhite populations (Brady et al. 1993, Brady et al. 1998, Roseberry and Sudkamp 1998). We calculated a Pearson's correlation coefficient between northern bobwhite abundance and cropland cover for each state and physiographic region using the randomly sampled cells within each state and physiographic region, respectively, for all 3 time periods. For the moving window analysis, 400×400-km² windows were defined and moved systematically across northern bobwhite range in 80-km steps. For each window with ≥80% of its area within northern bobwhite range, a Pearson's correlation coefficient between northern bobwhite abundance and cropland cover was calculated based on the randomly sampled cells that fell within the moving window for each of the 3 time periods. An ArcView script was developed for defining and evaluating the moving windows and calculating the correlation coefficients between selected variables for each window. There was a total of 465 qualified 400×400-km² moving windows with 80-km steps within northern bobwhite range. This approach effectively resulted in an 80×80-km² grid over northern bobwhite range.

RESULTS

When the entire range of the northern bobwhite addressed by the BBS was considered, abundance declined since the late 1960s (Fig. 1). Trends in bobwhite

abundance, however, varied considerably spatially, either exhibiting no trend or increasing in many western and northern portions of this species' range, particularly between 1978 and 1987 (Fig. 2).

Cropland cover (Fig. 3A) increased dramatically between 1978 and 1987 in most of Nebraska and Kansas, probably at the expense of rangeland (Fig. 3B), and continued to increase between 1987 and 1997. Loses of cropland cover occurred over this entire period in much of Tennessee, Texas, eastern South Carolina, and the coastal bend of Florida. Where changes in cropland cover were observed in most of the remaining northern bobwhite range, they were typified by decreases from 1978 to 1987, and increases from 1987 to 1997. Some of the loses in rangeland cover (Fig. 3B) that occurred in most of Nebraska, Kansas, Oklahoma, and the Texas Panhandle between 1978 to 1987, reversed from 1987 to 1997. Conversely, rangeland gains occurring in west and south Texas during 1978 to 1987, became loses between 1987 to 1997. In general, rangeland was lost over much of Florida during these 2 decades. Woodland cover (Fig. 3C) was lost over most of the southeastern United States between 1978 and 1987. From 1987 to 1997, however, these losses largely were terminated, and increased woodland cover was seen in parts of Mississippi and along the South Carolina-Georgia border. Between 1987 and 1997, most increases in CRP/WRP coverage (Fig. 3D) extended from west Texas, through western Kansas, into southern Iowa and northern Missouri. From 1978 through 1997, average farm/ranch size (Fig. 3E) increased over much of the Mississippi valley, from coastal southern Virginia through southwestern Georgia, and in Kansas, but decreased during this period in much of southwestern Texas. Interestingly, portions of Nebraska, eastern New Mexico, and Florida that experienced marked decreases in the average farm/range size between 1978 and 1987, saw dramatic increases from 1987 to 1997. The converse was the case along the southeastern corner of New Mexico and part of far south Texas.

While there were obvious spatial and temporal patterns in the landuse variables we considered (Fig. 3A–E), there were no clear relationships among any of these variables and northern bobwhite abundance that could universally be applied across this species' range (Table 1). Interestingly, associations between northern bobwhite abundance and the crops considered negative or positive were not consistent across the 3 time periods. Further, cotton cover and northern bobwhite abundance were positively, though weakly, related. The results were no more convincing when we used multivariate approaches to regress northern bobwhite abundance against the landuse variables and main factors resulting from factor analysis ($r^2 = 0.23$ – 0.32 and 0.08 – 0.15 , respectively). Clearly, no single landuse variable or group of variables we evaluated can account for northern bobwhite abundance patterns across this species' range.

Because the state-based assessment of the relationship between cropland cover and northern bobwhite abundance was biologically arbitrary, it was potential-

ly misleading ecologically (Fig. 4A). In Texas, for instance, this analysis suggested that cropland cover had little to do with northern bobwhite populations—an unreasonable conclusion. The assessment based on physiographic regions appeared more appropriate (Fig. 4B). For example, our analysis found a strong positive relationship between cropland cover and northern bobwhite abundance in the Edwards Plateau of Texas, a region typified by rangeland (Fig. 3B; Hatch et al. 1990), as had earlier field surveys (Reid et al. 1979). Analysis based on physiographic regions, while more useful than the statewide summary, still misrepresented the spatial patterns inherent in the relationship between northern bobwhite abundance and cropland cover. For example, if physiographic regions are the spatial unit of interest, one is led to believe that there was a markedly negative relationship between cropland cover and northern bobwhite abundance in the southwestern extreme of this species' range during the 5-year periods centered on 1978 and 1987, that suddenly became strongly positive during the 5-year period bracketing 1997 (Fig. 4B). Again, this is unreasonable. The moving window approach was unique in that it provided spatially consistent and temporally persistent patterns (Fig. 4C). For these reasons, the results of the moving window analysis are much more conducive to the development of sound, broadly applicable ecological interpretations of the cropland cover–northern bobwhite relationship that can serve as the basis for defensible management recommendations.

DISCUSSION

There is no question that determining why northern bobwhite abundance has declined over vast areas (Figs. 1–2) is important to hunters, bird watchers, and biologists alike. For various reasons, most quail biologists have studied northern bobwhites at the pasture spatial scale. Such efforts, while excellent for some purposes, are unlikely to explain why northern bobwhite abundance has declined at the physiographic region or continental spatial scales—far too few pastures can be evaluated.

Fluctuations in northern bobwhite abundance among years have long been recognized (Stoddard 1931:339–347, Rosene 1969:194–197, Schwartz 1974, Snyder 1978, Roseberry and Klimstra 1984: 151–191) and are particularly noticeable in semiarid areas such as western Texas (Peterson and Perez 2000, Peterson 2001). In semiarid regions at least, these fluctuations can largely be explained by weather (Bridges et al. 2001; Lusk et al. 2001, Under Review). The fact that weather can explain fluctuations in northern bobwhite abundance among years, however, does not necessarily imply that it is responsible for observed long-term trends in bobwhite numbers (Figs. 1–2). For this to have been the case, significant climatic changes, such as global warming (Guthery et al. 2000a), would have had to have occurred since the early 1970s.

If global warming, or other climate changes, are not solely responsible for long-term trends in northern



Fig. 4. Correlation between the 5-year mean number of northern bobwhites observed during the North American Breeding Bird Survey (Sauer et al. 2000) centered around 1978, 1987, and 1997 and cropland cover by (A) state, (B) physiographic region, and (C) 400×400-km² moving windows (displayed as an 80×80-km² grid) from the county-level Census of Agriculture (USDA-NASS 2000) data, based on 100,000 randomly selected data points from the interpolated data.

bobwhite abundance, then human-influenced habitat changes are likely involved (Brennan 1991, 1993; Church and Taylor 1992, Brady et al. 1998). While the relationship between northern bobwhite abundance and various landuses have been evaluated at broad spatial scales in certain locales (Brady et al. 1993; Roseberry and Sudkamp 1998; Lusk et al. 2001, Under Review), few studies have addressed the entire range of this species (but see Brady et al. 1998). In our attempt to address this deficiently, we found that none of the univariate or multivariate landuse-based explanations for trends in northern bobwhite abundance that we evaluated could appropriately be applied across this species' range (Table 1). It certainly is possible, however, that fluctuations in bobwhite abundance might respond in a strongly nonlinear fashion to ≥ 1 landuse variable (Lusk et al. 2001, Under Review), or that threshold-based state transitions occurred. These possibilities warrant further investigation.

It also was apparent that dramatic spatial and temporal variation in landuse typified northern bobwhite range in the United States (Fig. 3A–E). Quail biologists probably have suspected this for many years. For example, quail managers commonly argue that ranch fragmentation in much of Texas contributed to declin-

ing quail abundance, while their colleagues east of the Appalachians, from Virginia through Georgia, often argue that increasingly clean farming occurring on larger and larger farms was the problem. Both groups may be correct (Fig. 3E). Because of the spatial and temporal variation in landuse (Fig. 3A–E), as well as quail abundance (Fig. 2), it seems obvious that both spatially and temporally explicit analyses, covering vast areas, will be required to explain the trends in northern bobwhite abundance illustrated in Figure 2.

Although our failure to delineate a single, universal landuse-based explanation for trends in northern bobwhite abundance is inconvenient for managers, it should not be surprising. For example, even when only the western portion of northern bobwhite range was considered, bobwhite population dynamics still varied dramatically by latitude (Guthery et al 2000b). Similarly, while it might be fair to say that the northern bobwhite is an early successional species in forested areas of the southeastern United States, this certainly is not the case in the rangelands of Texas and Oklahoma. Guthery (1999) maintained that viable populations of northern bobwhites could exist under a wide variety of habitat configurations, but that boundaries existed affecting whether space could be used by

bobwhites—thus affecting abundance. Again, spatially explicit, regional variations in the northern bobwhite-landscape relationship are likely an important reason for the lack of a simple, all encompassing relationship among landuse and bobwhite abundance.

It also should not be surprising that the state-based assessment of the relationship between cropland cover and northern bobwhite abundance (Fig. 4A) was not particularly useful. After all, political boundaries are largely arbitrary as far as northern bobwhites are concerned. While assessments based on physiographic regions (Fig. 4B) were much more functional, they still misrepresented the spatial pattern inherent in the relationship between cropland cover and northern bobwhite abundance in many regions. Two possible explanations for this fact come to mind. First, perhaps the classification of physiographic regions was not sufficiently fine to represent natural ecological divisions pertinent to northern bobwhites. Second, although the physiographic regions might be fair representations of the natural divisions of major ecosystems, the functions of these ecosystems as northern bobwhite habitat unquestionably have been modified, sometimes severely, by human activities. This could lead to altered spatial patterns of habitat distribution (Guthery 1999) that are driven by both biophysical and anthropogenic processes as well as their interactions.

The spatially consistent and temporally persistent patterns obtained by allowing data to define the spatial patterns associated with cropland cover and northern bobwhite abundance (Fig. 4C) suggests that scientifically sound, broadly applicable ecological interpretations of this relationship are possible. For example, Roseberry and Sudkamp (1998), Lusk et al. (2001), and Lusk et al. (Under Review) found optimal levels of cultivation for northern bobwhites to be between 30 and 65% across Illinois, 40–50% in western Oklahoma, and ~20% in 6 western physiographic regions of Texas, respectively. Thus, because the optimal level of cultivation for northern bobwhites varies spatially, data-driven, spatially explicit analyses should be able to reliably explain why such patterns persist over time.

The patterns illustrated in Figure 4C may well reflect the combined influence of multiple factors, not simply cropland cover. The existence of these patterns, however, should help biologists determine which landuse variables most influence northern bobwhite abundance in a spatially explicit fashion, and how changes in these factors influences northern bobwhite populations in different areas of this species' range. Evaluating other landuse variables, such as those listed in Table 1, using a moving window approach and various sized moving windows, would be excellent initial steps. This same general approach also could be used to evaluate the relationship between northern bobwhite abundance and individual crops, human density, or other factors of interest. Further, since many biologists maintained that northern bobwhite abundance has been declining for at least 100 years (Leopold 1931:26, Stoddard 1931:xxi, Errington and Hamerstrom 1936:382, Lehmann 1937:8), longer-term bobwhite and lan-

duse data also should be employed. We contend that such analyses are essential to formulating defensible, spatial explicit strategies for northern bobwhite conservation and management designed to maximize the amount of habitat space available through time (Guthery 1997), thus allowing bobwhites to take advantage of their genetically derived ability to make use of diverse habitats (Guthery 1999).

SUMMARY AND IMPLICATIONS

Although northern bobwhite abundance typically decreased at the rangewide spatial scale (1966–99; Fig. 1), trends in abundance varied considerably spatially (Fig. 2), either exhibiting little trend or increasing in certain western and northern portions of this species' range. While both spatial and temporal patterns in landuse were obvious and intriguing (Fig. 3), there were no clear univariate or multivariate relationships among these variables and northern bobwhite abundance that could appropriately be applied across this species' range (Table 1). In other words, we found no data supporting a single landuse-based "rule of thumb" that could universally explain long-term trends in northern bobwhite abundance across this species' range.

Our exploration of the relationship between cropland cover and northern bobwhite abundance at various spatial scales was revealing. First, using political boundaries, such as state lines, to explain ecological phenomena is likely to be misleading at best (Fig. 4A). Political boundaries typically have little relevance to northern bobwhite populations. Although assessments based on physiographic regions were much more useful (Fig. 4B), they still sometimes misrepresented the spatial pattern inherent in the relationship between cropland cover and northern bobwhite abundance in several regions. Perhaps physiographic regions were not sufficiently fine to represent natural ecological divisions pertinent to northern bobwhites, or the spatial patterns of habitat was altered by anthropogenic activities and their interactions with biophysical processes. Lastly, our moving window approach, which allowed data to define the spatial patterns associated with cropland cover and northern bobwhite abundance, was unique in that it provided spatially consistent and temporally persistent patterns (Fig. 4C). These consistent, yet persistent patterns suggest that scientifically sound, broadly applicable ecological interpretations of the cropland cover-northern bobwhite relationship are possible.

Scientifically defensible, spatially explicit management plans for northern bobwhites are badly needed. While the spatially consistent, yet temporally persistent patterns between cropland cover and northern bobwhite abundance (Fig. 4C) suggest that landscape-based explanations for relative quail abundances should be possible, these patterns may well reflect the combined influence of multiple factors (Fig. 3B–E), not simply cropland cover. For this reason, we suggest that moving windows-based analyses, exploring multiple window dimensions, be used to evaluate the ef-

fects and scaling of numerous landuse variables thought to be important to northern bobwhites. Further, many biologists' perception that northern bobwhite abundance began declining in the early 1970s is likely a function of when the BBS began. For this reason, future analyses should start much earlier by either taking advantage of COA data not available electronically (or other long-term landuse data), and northern bobwhite abundance surveys beginning prior to the BBS. Analyses of this type are essential to formulating defensible, spatially explicit strategies for northern bobwhite conservation and management designed to maximize the amount of habitat space available through time across this species' range.

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