Ecological Applications, 13(2), 2003, pp. 432–442

MILITARY TRAINING EFFECTS ON TERRESTRIAL AND AQUATIC COMMUNITIES ON A GRASSLAND MILITARY INSTALLATION

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Abstract. Understanding the link between terrestrial and aquatic systems is important because disturbance to terrestrial systems may also influence stream processes. Military training lands provide a unique opportunity to examine the influence of large-scale disturbance on terrestrial and aquatic communities in the absence of other anthropogenic disturbances (e.g., agriculture, urbanization). The objective of this study was to determine the effects of past mechanized infantry training on terrestrial and aquatic ecosystem properties on Fort Riley Military Reservation in northeastern Kansas. We used a long-term data set and supplemental study plots to determine the effects of military training use on terrestrial systems. Headwater and middle stream reaches were also sampled to determine the effects of watershed training use on habitat and fish community structure. High military training use was associated with increased bare soil, reduced total plant cover, and compositional shifts in plant communities. Reduced cover of perennial, matrix-forming grasses and native species, and increased cover of annuals and introduced species were also associated with high training activity. High military training use in study watersheds was associated with increased sediment in pools and riffles and reduced abundance of benthic insectivores, herbivore–detritivores, and silt-intolerant species. Sites in watersheds receiving high training use were also characterized by an abundance of trophic generalists and tolerant species. Our results suggest that military training activities had significant ecological effects on the properties of terrestrial and aquatic ecosystems, both with respect to recovery from past disturbance and resilience to future disturbance.

Key words: community structure; disturbance; Flint Hills; Fort Riley Military Reservation, Kansas; tallgrass prairie; military training; watershed.

INTRODUCTION

Since the settlement of the Great Plains grasslands of North America, human land use has increasingly dominated native grassland systems. Historically, the structure and function of these grasslands was primarily a function of interactions among climatic variability, native ungulate grazers, and periodic fires (Knapp et al. 1998). The aquatic systems draining these grasslands display community structure and productivity dynamics dominated by patterns of terrestrial runoff, which is in turn governed by variability in precipitation patterns, underlying geology, and characteristics of terrestrial vegetation cover (Axelrod 1985, Matthews 1988, Resh et al. 1988). Central Plains grasslands now occupy a fraction of their original area due to the expansion of row-crop agriculture and urban areas. The remaining native grasslands have experienced alterations in climatic regimes, replacement of native grazers by domestic cattle, changes in fire frequency, and introductions of non-native invasive species, leading to shifts in the species composition and productivity of both terrestrial and aquatic systems (Knapp et al. 1998, Kemp and Dodds 2001, Schrank et al. 2001).

In some parts of the Central Plains, grasslands controlled by the U.S. Army are subject to additional impacts from training exercises. Typical military land use includes maneuvers by large, tracked and wheeled vehicles that can traverse thousands of hectares in a single training exercise. These activities cause impacts ranging from minor soil compaction and lodging of standing vegetation to severe compaction and complete loss of vegetative cover in areas with concentrated training use (Wilson 1988, Milchunas et al. 1999). Some military training sites are larger than many national parks and refuges, are often relatively isolated, and have experienced little or no urbanization (Cohn 1996). As a result, these ecosystems are also increasingly important reserves of habitat for populations of native species

Manuscript received 15 August 2001; revised 3 May 2002; accepted 7 July 2002. Corresponding Editor: M. G. Turner.

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(Shaw and Diersing 1989, Cohn 1996). Thus, military land managers face the conflicting demands of balancing the primary military mission with legal requirements to protect land and water quality and endangered species (U.S. Army 1994, Cohn 1996, Milchunas et al. 1999).

In response, the Army has developed the Land Condition Trend Analysis (LCTA) program to systematically monitor terrestrial impacts from military training and to support the mitigation and remediation of severely impacted training lands. Because of the functional linkages between terrestrial and aquatic systems, an important question is whether the terrestrial LCTA monitoring program can be used to predict changes in aquatic systems caused by terrestrial training activities. The U.S. Army manages $\sim 4.8 \times 10^6$ hectares of land for military training and in some grassland regions, Department of Defense lands account for over 75% of all federal land holdings (Shaw and Diersing 1989). Thus, the utility of LCTA to account for both terrestrial and aquatic communities is important for military land managers. In addition, comprehensive studies have not been conducted to determine the influence of training on aquatic communities. Therefore, this study sought to determine to what extent LCTA monitoring of accumulated military training use and terrestrial plant cover and composition served to characterize stream ecosystem properties at an Army installation in mesic tallgrass prairie in northeastern Kansas.

Study Area

Fort Riley Military Reservation is a 40 200-ha U.S. Army installation in northeast Kansas. Fort Riley was established in 1853 and currently serves as a combat training ground for mechanized infantry units. Large numbers of tanks, artillery, tracked-personnel carriers, and support vehicles engage in spatially extensive, year-round maneuver training (U.S. Army 1994). These maneuvers are generally concentrated in a 26 400-ha area in the central and northern portions of the installation (Fig. 1).

Fort Riley is on the western edge of the Flint Hills, a region in eastern Kansas that contains the largest contiguous remnant of tallgrass prairie in North America (Bragg and Hulbert 1976, Zimmerman 1985, Lauver 1994). The eastern portion of Fort Riley displays topography and vegetation typical of the Flint Hills, with an underlying substrate of alternating layers of limestone and shale, and vegetation dominated by a group of highly productive, warm-season C_4 grasses mixed with a diverse assemblage of annual and perennial forbs (Freeman 1998). The western portion of Fort Riley exhibits less relief, deeper soils, and a plant community undergoing succession back to native prairie from cultivation prior to annexation by the Army in the 1960s.

Fifteen streams are located on Fort Riley, including portions of the Kansas and Republican rivers. Most of the streams are perennial due to groundwater inputs and few are impounded. Nearly all of the streams originate in the central portion of Fort Riley and are completely contained within the boundaries of the installation (Fig. 1). Riparian vegetation is confined to relatively narrow corridors along the streams, covering ~5–10% of the installation. Dominant riparian species include *Quercus* spp. and *Celtis occidentalis*.

The streams of Fort Riley are typical of streams in the Flint Hills, having relatively steep gradients with eroded limestone and shale forming the dominant substrate (Metcalf 1966). Due to the lack of intensive row-crop agriculture and other large-scale anthropogenic disturbances, most Flint Hills streams have well-developed pool–riffle sequences and large substrates (Tripe and Guy 1999). In addition, Flint Hills streams support the most diverse fish fauna in the Kansas River Basin (Metcalf 1966), and in many streams, the fauna includes threatened and endangered species, such as *Notropis topeka*.

Methods

Our study consisted of three major components: (1) determining the accumulated level of impacts from military training activity on terrestrial vegetation cover and species composition as indicated by LCTA monitoring on Fort Riley from 1989 through 1996, (2) a detailed assessment of vegetation cover and species composition on supplemental transects, and (3) characterization of stream habitat quality and fish communities.

Disturbance history and vegetation

The accumulated levels of military land use impacts and vegetation cover and composition in the study watersheds were compiled from 79 permanent LCTA transects, a subset of 160 permanent LCTA transects. The transects were sampled once each growing season. Because of access limitations imposed by military training activities, sampling was conducted from May through August each year.

Transect sampling procedures followed LCTA standard methods (Diersing et al. 1992, Tazik et al. 1992). Observations were made at 1-m intervals along each 100-m transect. Each point was assigned to one of five standard categories of visually evident military training use (none, pass, trail, road, other). Most sample points (68% of all observations between 1989 and 1996) recorded no visible evidence of military training use. When a disturbance from training was observed, most (30%) were assigned "pass," which describes lodged vegetation or other impacts from random, one-time vehicle passage. The other categories (trail, road, and other) were assigned to only 2% of the observations. These categories denote more persistent impacts, such as regularly used off-road vehicle paths or various nonvehicular disturbances. The training use categories do not describe when training occurred, only that there was visual evidence of training use at the time of observation. Wildfires and prescribed burns were not accounted for in our analysis, since Fort Riley does not maintain records of the locations of wildfires or prescribed burns.

A military training index was estimated for each year by tabulating the number of points per transect with evidence of military training use, converting to percent, and then averaging over the eight years of sampling (1989–1996). Mean military training index values over all transects and years was 31.8% (SD = 19.0; CV = 86.0). The coefficient of variation decreased in transects with high mean training index values ($r = -0.71$, $P = 0.0001$), indicating that plots with high frequencies of observed impacts tended to be consistently high through time due to either early, persistent impact, or repeated use. Weighting schemes to incorporate the severity or persistence of each training use category (e.g., pass, trail) were considered in preliminary analyses, but had little effect on training index values and were omitted.

When the observations were made to assess military training impacts, vegetation cover and species composition were also characterized using a point-intercept method. If no vegetative cover was present, the sampling point was categorized as bare soil, and the number of such points was used as an estimate of percent bare soil for each transect. Species richness and the Shannon diversity index were also calculated for each transect.

To corroborate and extend the LCTA characterization of training use and plant community structure, 20 supplemental 60-m transects were established in 1996 throughout the study watersheds where nearby LCTA transects and site visits indicated either high (80.9 ± 0.04 [mean training index ± 1 SE]) or low (25.5 ± 0.04) levels of military training use (Fig. 1). Supplemental transect locations were chosen to minimize topographic variation, an important influence on plant species composition in the Flint Hills (Knapp et al. 1998). Training use was quantified with LCTA methods along each transect. In addition, three 10-m^2 circular subplots were overlaid on the transect to further quantify cover of each plant species and bare soil. A modified Daubenmire technique (Daubenmire 1959) was chosen because this method records more species than the point-intercept method. Vegetation was sampled on the subplots in mid-June and August in 1996 and 1997, and the maximum cover value for each species was retained for analysis. Species cover was tabulated by life history strategy (annual, perennial) and growth form (forb, grass), and used to calculate species richness and diversity. All but one supplemental transect burned at least once in either prescribed or accidental fires during the study.

Aquatic community sampling

Stream habitat and fish communities were sampled during June and July 1997 and 1998 from 14 reaches in 10 streams (Fig. 1). The 14 reaches were delineated as headwater or middle (mid-) reaches based on drainage area (headwater = 0.0–9.0 km^2 and mid-reaches = 9.1–20.0 km^2). Two sites were randomly selected per reach for sampling of habitat and fish community characteristics. Site length was generally 35 times the mean stream width (Lyons 1992, Simonson et al. 1994), with a maximum length of 300 m. Preliminary analyses indicated that habitat and fish communities were similar between years; therefore, sites and years were aggregated by stream and reach for a total of eight headwater and six mid-reaches (Fig. 1).

Habitat and fish community sampling was conducted in 112 pool and 106 riffle macrohabitats within these reaches. Well-defined run macrohabitats were absent. Stream width, depth, current velocity, and substrate particle size were measured at four equidistant points and the midpoint along transects spaced at 0.25 and 0.75 times the length for macrohabitats ≤30 m long and at 0.25, 0.50, and 0.75 times the length for macrohabitats >30 m. Mean water column velocity was measured with a Marsh-McBirney Flowmate 2000 flowmeter (Marsh-McBirney, Incorporated, Frederick, Maryland, USA) following the guidelines of Buchanan and Somers (1969). Substrate particle size was classified on a modified Wentworth scale (Cummins 1962), except for the inclusion of a bedrock category and pooling of sand categories. Riparian canopy cover was measured with four readings from a spherical densiometer at the stream margins, and upstream and downstream at the midpoint of each transect (Murphy et al. 1981). Stream morphology and riparian cover data were averaged by macrohabitat for both reach types.

Fish communities were sampled by conducting one upstream-electrofishing pass per macrohabitat with a Smith-Root Model 15-C backpack electrofisher (Smith-Root Incorporated, Vancouver, Washington, USA), supplemented by two seine hauls (bag seine: 7.6 × 2.0 m with a 1.0 × 1.0 m bag and 6.0-bar mesh; Hoyt et al. 1979, Bayley and Dowling 1990, Reynolds 1996). All fish were identified in the field and counted. Each fish species was categorized into trophic guilds (Schlosser 1982, Gorman 1988, Cross and Collins 1995, Pflieger 1997): benthic insectivore, generalized-insectivore, herbivore–detritivore, insectivore–piscivore, omnivore, and surface- and water-column insectivore (see Appendix). Several species were also categorized as tolerant or intolerant of sedimentation based on their habitat and reproductive requirements (Cross and Collins 1995, Pflieger 1997). The abundance of fishes by species, trophic guilds, and tolerance categories was indexed as catch per unit of effort (C/f = number of fish per minute of electrofishing). Seining and electrofishing data were combined to calculate species richness and Shannon's index.

Statistical analyses

Associations of plant and bare soil cover with mean training index values were quantified by regression

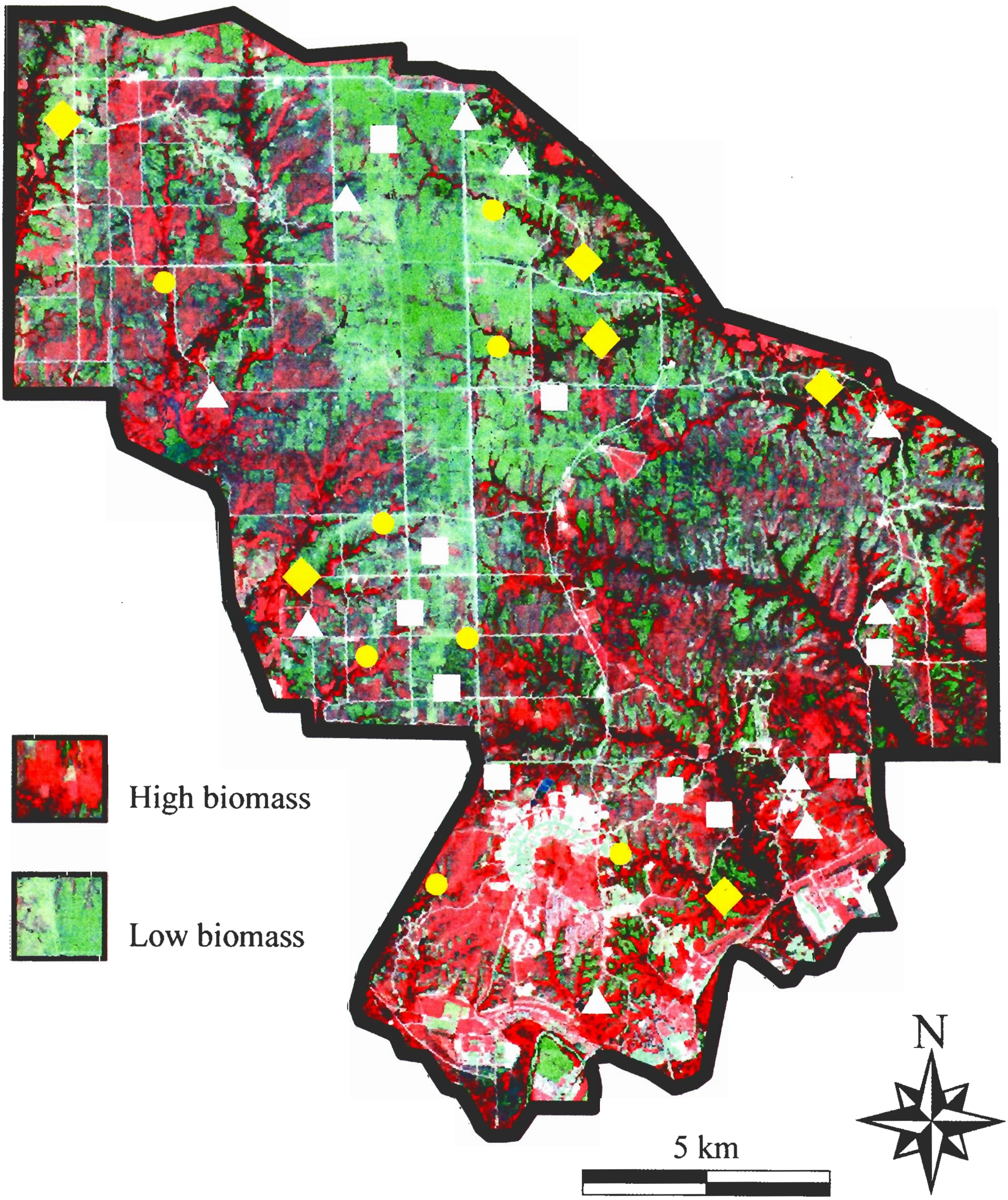

FIG. 1. Satellite image of Fort Riley Military Reservation in the Flint Hills region of northeast Kansas (1997). Light green regions indicate areas of low vegetative biomass, and red areas are regions of high biomass. White squares (high training use) and triangles (low training use) represent supplemental transects sampled during June and September 1996 and 1997. Yellow symbols represent headwater (circle) and middle (diamond) stream reaches sampled during 1997 and 1998.

analysis (Ott 1993). The LCTA and supplemental transects were pooled in the regressions because preliminary analyses indicated similar relationships for the two transect types. Plant cover by species, growth form (grass or forb), life history (annual or perennial), and origin (native or introduced) of plants on supplemental transects were assessed using repeated-measures analysis of variance (ANOVA; Littell et al. 1996). Frequency of silt substrate, fish abundance, and training index associations were examined with separate re-

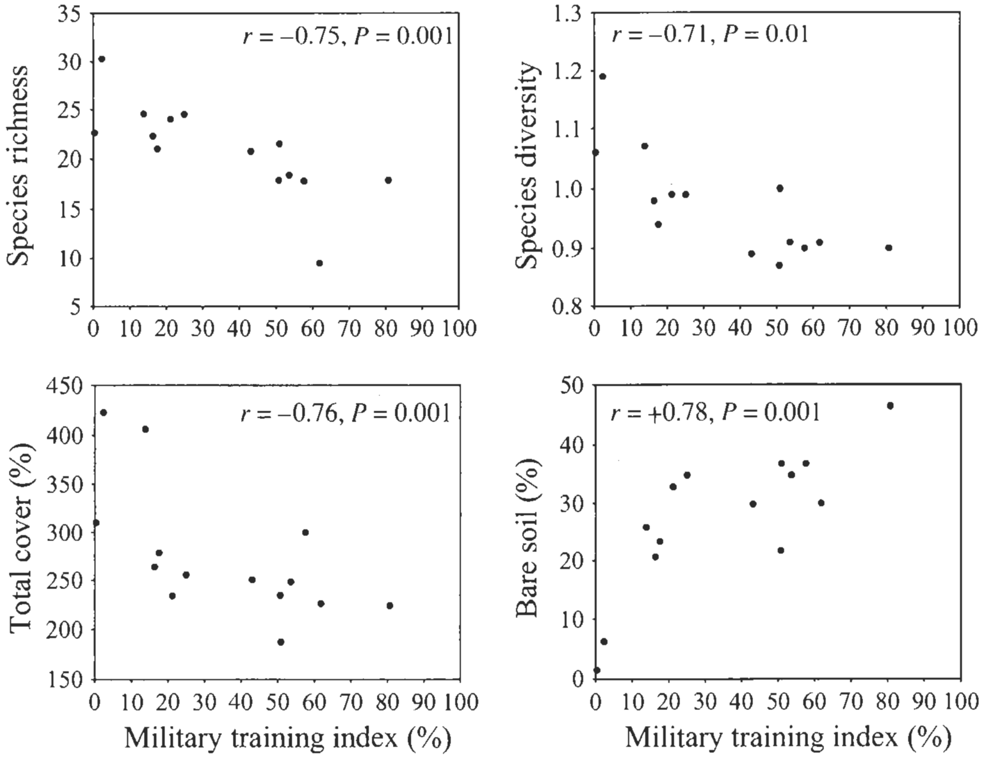

FIG. 2. Relationships between mean training index values and species richness, species diversity (H'), total cover of vegetation, and bare soil in watersheds surrounding stream reaches on Fort Riley Military Reservation, Kansas (USA).

gressions for pool and riffles in headwater and mid-reaches. Mean training index values, fish functional group abundance, species richness, and diversity in pool and riffles were compared between reaches using ANOVA.

RESULTS

Disturbance history and vegetation

Military training activities varied considerably in the study watersheds. Several watersheds had training use index values <25%, but the majority were >50% (Fig. 2). Training activities were strongly associated with plant community characteristics and the amount of bare soil (Fig. 2). Plant species richness, species diversity, and total cover decreased with increased training use of the watershed. Conversely, cover of bare soil increased with military training use, reaching over 35% on several areas.

Examination of the training use index values in Fig. 2 indicates two broad categories of military training: low use (<30%) and high use (>40%). Therefore, cover of vegetation on supplemental transects was pooled into either high or low training use categories (Fig. 3). High military use was associated with reduced cover of perennial grasses (e.g., *Adropogon gerardii*, *A. scoparius*), perennial forbs (e.g., *Artemisia ludoviciana*, *Schrankia nuttallii*), and native species (e.g., *Andropogon* spp., *Sporobolus asper*), and increased abundance of annuals (e.g., *Aristida oligantha*, *Helianthus annus*) and introduced species (e.g., *Bromus inermis*, *Lespedeza stipulacea*).

Aquatic habitat and fish community characteristics

Military training use in the watershed was strongly associated with habitat quality and fish community composition. Military training index values were significantly higher ($P = 0.02$) in headwater reaches (47.6% ± 8.0 [mean ± 1 SE]) compared to mid-reaches (18.7% ± 5.6). Mean depth, current velocity, and width were generally higher in mid-reaches compared to headwater reaches, but the differences were not significant ($P > 0.05$). Riparian canopy cover averaged over 80% at all sites and was not significantly different between reaches or habitat types ($P > 0.05$). The proportion of silt substrate in riffle habitats was similar ($P = 0.99$) between headwater (33.7% ± 11.7) and mid-reaches (33.7% ± 8.8), while pools from headwater reaches (65.4% ± 6.7) had significantly more silt substrate ($P = 0.02$) than mid-reaches (38.3 ± 7.7). Military training index values in the watershed were positively correlated with percent silt substrate in pools and riffles from both reach types (Fig. 4).

Fishes representing 29 taxa and 6 families were sampled from all of the study reaches. Fish species richness and diversity were lower in headwater reaches compared to mid-reaches and was especially evident in pool macrohabitats (Table 1). Similar to terrestrial plant communities, military training in the watershed was an important factor influencing fish community composition. Species richness and diversity in headwater reaches were inversely correlated with training index values, but the relationships were not significant (Table

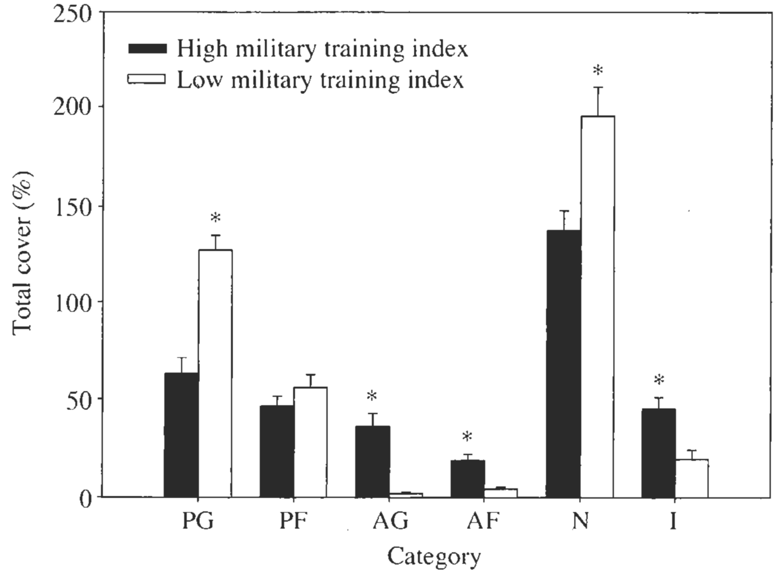

FIG. 3. Total cover of vegetation by life history and growth form on supplemental transects grouped into high and low training-use categories (see *Methods, Disturbance history and vegetation*). Key to abbreviations: P, perennial; A, annual; G, graminoid; F, forb; N, native; I introduced). Error bars represent one standard error. An asterisk represents a significant difference ($P \leq 0.05$) between plots with histories of high and low military training use.

1). Species richness and diversity in headwater reaches were relatively low and exhibited low variation, which likely explains the lack of statistically significant results. Fish species richness and diversity showed opposite trends at mid-reach sites where richness and diversity increased with military training use.

Silt-tolerant species and omnivores (e.g., *Pimephales promelas*) often dominated fish communities in headwater reaches, but their abundance was not correlated with training index values in the watershed ($r < 0.40$, $P > 0.05$). Rather, catch rates of benthic insectivores (e.g., *Etheostoma spectabile, Catostomus commersonii*), herbivore–detritivores (i.e., *Campostoma anomalum*), and silt-intolerant species (e.g., *E. spectabile, Phoxinus erythrogaster*) in headwater reaches decreased in pool and riffle macrohabitats with increased military training (Fig. 5). In mid-reaches, abundance of insectivore–piscivores (e.g., *Lepomis cyanellus, L. humilis*), omnivores (e.g., *Pimephales promelas, P. notatus*), and silt-tolerant species (e.g., *Pimephales* spp., *Cyprinella lutrensis*) increased with military training use in the watershed (Fig. 6). These trends are attributed to increased abundance of individual species (e.g., *L. cyanellus, Pimephales promelas*), as well as species additions (e.g., *Cyprinus carpio, Ameiurus natalis, Gambusia affinis*). *Notropis topeka* (a federally endangered species) were not sampled in any of the headwater reaches; rather, they were only sampled from sites (Wind and Little Arkansas creeks) with little military training use (i.e., <20%) and a relatively low proportion of silt substrate in pool habitats (i.e., <30%).

DISCUSSION

Military lands are considered important ecological reserves because they often encompass large tracts of

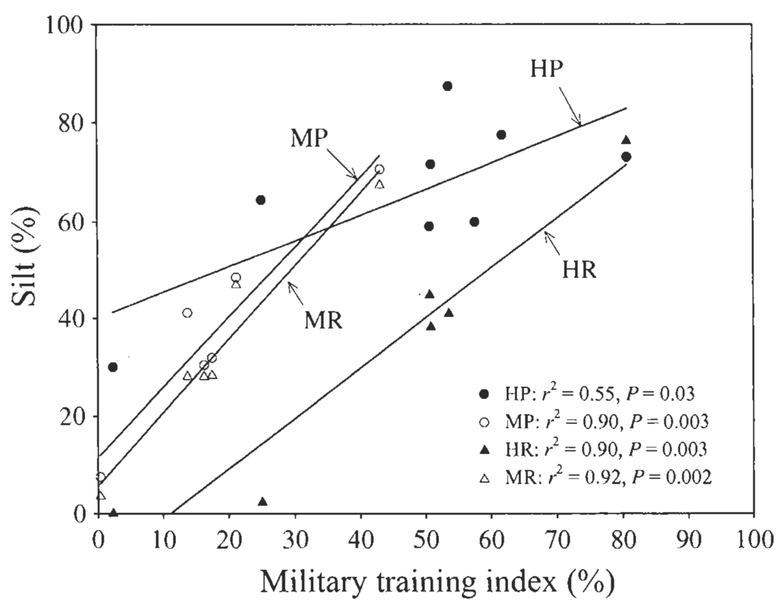

FIG. 4. Relationships between military training use and percent silt substrate in (P) pools and (R) riffles sampled from (H) headwater and (M) middle stream reaches sampled on Fort Riley Military Reservation during June and July 1998 and 1999.

TABLE 1. Mean species richness (S) and diversity (H') and relationships between military training index values within the watershed and species richness and diversity for pools and riffles sampled from headwater and middle stream reaches on Fort Riley Military Reservation, Kansas, during June and July 1997 and 1998.

Habitat	Mean (± 1 SE)		Relationships with military training index			
			S		H'	
	S	H'	r	P	r	P
Pool						
Headwater (N = 8)	2.6 (0.7)*	1.2 (0.4)	−0.41	0.30	−0.12	0.58
Middle (N = 6)	5.5 (0.7)	1.2 (0.1)	0.83	0.04	0.82	0.04
Riffle						
Headwater (N = 6)	0.8 (0.1)*	0.2 (0.1)*	−0.28	0.58	−0.75	0.08
Middle (N = 6)	1.2 (0.2)	0.4 (0.1)	0.83	0.04	0.18	0.74

* $P \leq 0.05$ between reach types.

land that are protected from intensive agriculture and urban development. However, military training activities involving large-vehicle maneuvers are a widespread land use that have been consistently shown to have negative effects across a variety of terrestrial ecosystems. These include training areas in California (Lathrop 1982, Prose 1985), Colorado (Milchunas et al. 1999), Washington (Severinghaus and Goran 1981), Wisconsin (Smith et al. 2002), Texas (Severinghaus et al. 1981), Manitoba (Wilson 1988), and western Europe (Vertegaal 1989). The extent of military lands indicates the importance of understanding the impacts from training. Although these studies have been conducted across a variety of ecosystems (e.g., desert, prairies), several generalizations have emerged. Milchunas et al. (1999) examined the effects of military vehicles on plant communities and soil characteristics in shortgrass steppe at Piñon Canyon Maneuver Site, Colorado. Cumulative military disturbances resulted in reduced abundance of perennial species, increased abundance of introduced species, and an increase in the amount of bare soil. Wilson (1988) examined the influence of tank traffic on terrestrial communities at a training site located in the mixed-grass prairie of Manitoba. Similar to studies in more arid ecosystems, tank traffic resulted in a significant loss of native species, increased abundance of introduced species, and increased bare soil. The results of our study fill an important gap in our understanding of military training effects on terrestrial systems. Despite differences in climate, geomorphology, and natural disturbance regimes among desert, shortgrass prairie, mixed-grass prairie, and tallgrass prairie, our results suggest that reductions in native, perennial grasses, increased abundance of introduced species, and increased bare soil (but see Smith et al. 2002) are a generalized response to military training.

Most of these studies have focused on the effects of large military vehicles (e.g., tanks), but the observed relationships probably relate to other vehicular disturbances (i.e., off-road vehicles). The impacts of off-road vehicles have been well documented in the California Mojave Desert and include destruction of soil invertebrate communities, soil compaction, reduced water infiltration, destruction of vegetation (especially perennial species), and increased erosion (see reviews in Webb and Wilshire 1982, Lovich and Bainbridge 1999). Parallel effects are observed with military traffic. The similarities between military and recreational impacts are not limited to vehicular disturbances. Recreational and military foot traffic have both been shown to adversely affect soil bulk density, infiltration rates, vegetation communities, and soil erosion (Trumbull et al. 1994, Whitecotton et al. 2000). The effects of recreational activities in tallgrass prairie have not been investigated in detail, but the high correspondence between recreational and military activities in other systems suggests that recreational activities may have effects similar to those observed in our study. Although a large number of studies have been conducted to assess the impacts of military training and recreational disturbances to terrestrial disturbances, similar studies on aquatic systems are nonexistent and represent a major gap in our understanding of the overall effects to the ecosystem.

Streams are functionally linked with their adjoining watershed (Schlosser 1991, Johnson and Gage 1997, Fausch et al. 2002). Consequently, the surrounding terrestrial ecosystem and its disturbance regime are important determinants of stream ecosystem properties (Hynes 1975, Vannote et al. 1980, Schlosser 1991). Although our results are correlative, they suggest a strong link between terrestrial disturbance from military training and stream degradation. The influence of terrestrial disturbance on instream habitat is well documented in forested systems (Greacen and Sands 1980, Chamberlin et al. 1991). For example, Reid and Dunne (1984) found that large vehicles increased sediment input to streams by 40% due to soil compaction and increased exposure of bare soil to rainfall and surface water runoff. On Fort Riley, a similar mechanism (i.e., bare soil, soil compaction) likely influenced the amount of silt in the study reaches. In addition to directly in-

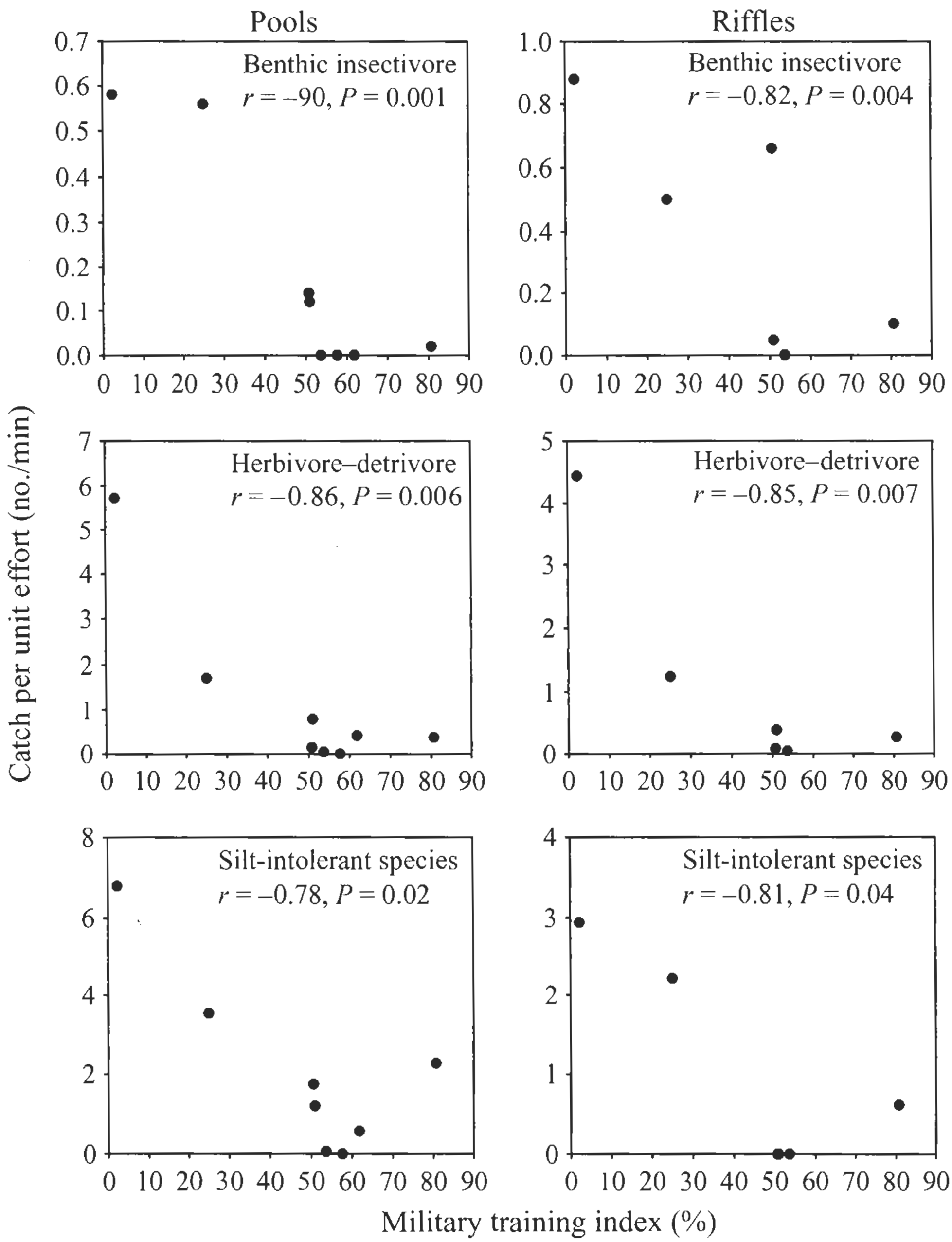

FIG. 5. Relationships between catch per unit effort (number of fish per minute of electrofishing) for trophic guilds and for tolerance categories and military training index values in headwater reaches of streams sampled on Fort Riley Military Reservation during June and July 1998 and 1999.

creasing the amount of bare soil, indirect effects on the plant community may also explain the observed patterns. Native, matrix-forming grasses, with their characteristic dense root systems, are often preferred in reclamation activities due to their ability to reduce surface erosion (Thames 1977). It was these native grasses whose abundance was reduced in watersheds receiving high training use on Fort Riley.

Stream reaches in watersheds that experienced high military training use were dominated by silt-tolerant species and trophic generalists. These results are important because fish communities dominated by trophic generalists and tolerant species are not characteristic of high-quality Flint Hills streams (Tripe and Guy 1999, Schrank et al. 2001) and generally indicate a decline in aquatic ecosystem health. In addition, the federally endangered *Notropis topeka* was only found in reaches with low training use in the watershed and a low proportion of silt substrate, suggesting the importance of watershed recovery for sensitive species.

An important question regarding the results of this study is how military training activities compares to the natural disturbance regime of the tallgrass prairie. Although fire is an important characteristic of tallgrass prairie (Knapp et al. 1998), military disturbances are probably most similar to grazing by large ungulates and disturbances by small mammal. Similar to vehicular activities, disturbance due to grazing activities by

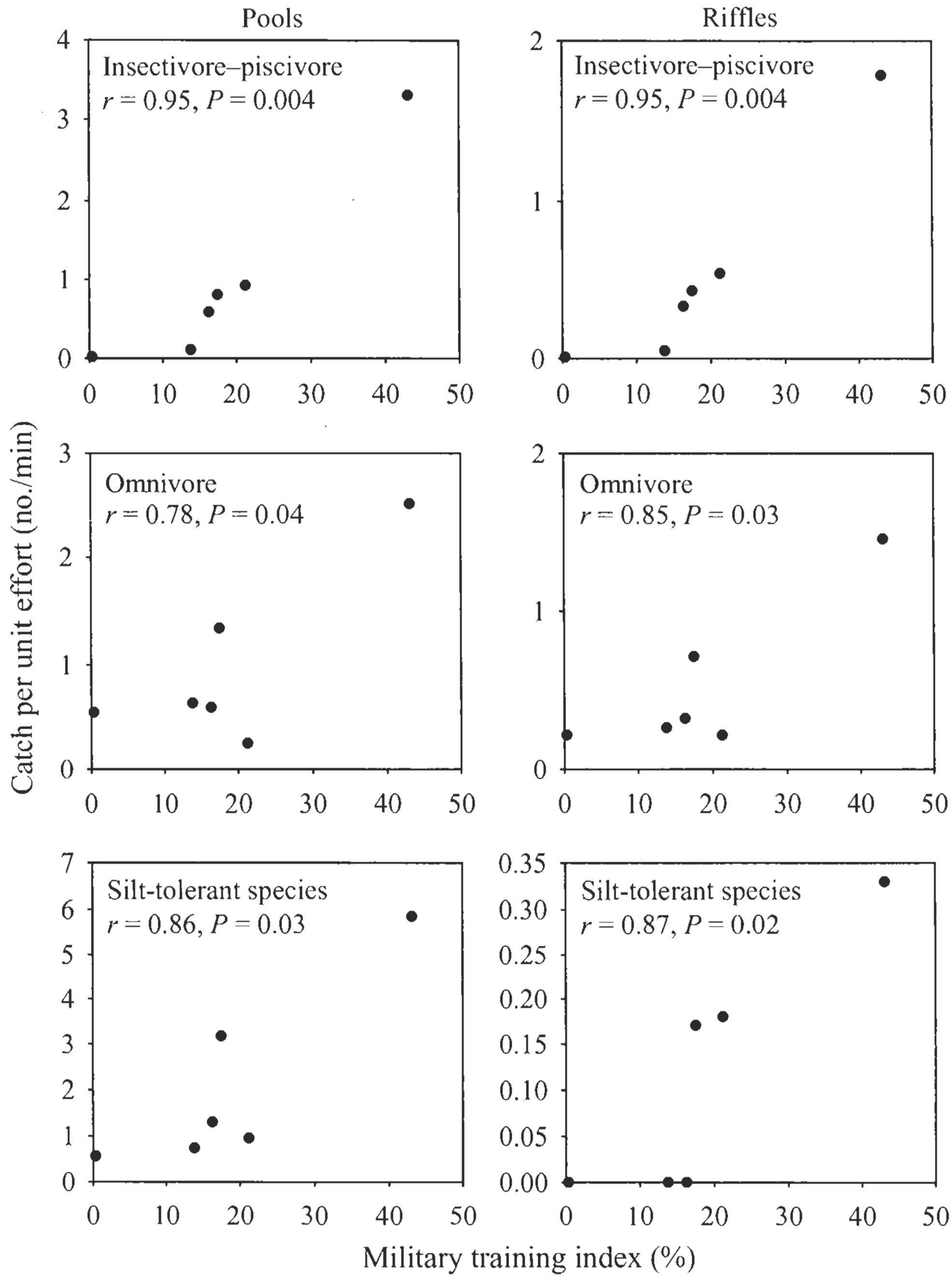

FIG. 6. Relationships between catch per unit effort (number of fish per minute of electrofishing) for trophic guilds and for tolerance categories and military training index values in middle reaches of streams sampled on Fort Riley Military Reservation during June and July 1998 and 1999.

ungulates or burrowing activities by small mammals increases the amount of bare soil. Research on the nearby Konza Prairie Biological Station (KPBS) has shown that subdominant native grasses and many perennial forbs are poor competitors in undisturbed tallgrass prairie, but typically increase following soil disturbances, such as those caused by mammalian activities (Knapp et al. 1998). We observed a similar pattern on Fort Riley, where several subdominant grasses and perennial forbs were more abundant in watersheds receiving high training use. Several studies have also shown that plant species richness increases with grazing by *Bos bison* (Knapp et al. 1999). Military disturbances resulted in an opposite trend on Fort Riley, which was primarily due to a shift from perennial grasses to a community dominated by annual and introduced species. These effects are not characteristic of native grazing, except in isolated areas where large ungulates congregate or wallow (McMillan 1999). We also find dissimilar effects with regard to aquatic systems. In Kings Creek (located within KPBS) watersheds exposed to *Bos bision* grazing, silt substrate averages 26.9% (SE = 0.08) for headwater stream reaches (C. S. Guy, *unpublished data*). Unfortunately, comparisons with streams not exposed to grazing are unavailable. Regardless, the only time we observed similar values on Fort Riley was when training index values were <30%. Therefore, military training activities appear to have a substantial influence on terrestrial and aquatic communities in tallgrass prairie, despite its history of complex natural disturbances.

Fort Riley encompasses over 40 000 ha in the largest remnant of tallgrass prairie in North America and has the potential to serve as an important reserve for terrestrial and aquatic ecosystems. Natural resource managers currently lack tools to assess and monitor aquatic systems, but our results suggest that LCTA data may be extended to predict military training effects on stream habitat quality and fish community characteristics. Military activities resulting in LCTA training index values <30% should be a target value for land managers on Fort Riley. When values were <30%, we observed a diverse plant community dominated by matrix-forming perennial grasses, low amounts of bare soil, a low proportion silt substrate, and fish communities more typical of less disturbed Flint Hills streams. Reaches with military training index values <30% were also the only sites where we found *Notropis topeka*. Whether or not these recommendations are applicable to other installations is unknown; however, the potential for ecological degradation over extremely large areas warrants similar studies across a variety of mililtary lands and ecosystems.

Acknowledgments

We thank N. Barger, M. Callaham, J. Delp, T. Elbel, T. Hungerford, G. Hoch, Z. Holden, S. Meng, G. Norris, A. Peckham, L. Quist, R. Ramundo, M. Smith, C. Stoffel, and J. Winn for assistance in the field and laboratory. M. Kemp, S. Proboszcz, and T. Strakosh provided information on stream characteristics from Kings Creek. Helpful comments by M. Turner greatly improved the quality of the manuscript. Funding was provided by the U.S. Army Corps of Engineers Research Laboratory, Konza Prairie Biological Station Long-Term Ecological Research Program, Kansas State University; Division of Biology, and the Kansas Cooperative Fish and Wildlife Research Unit (the unit is jointly sponsored by Kansas State University, Kansas Department of Wildlife and Parks, U.S. Geological Survey; Biological Resources Division, and the Wildlife Management Institute).

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APPENDIX

A table providing species, trophic guild, and tolerance category for fishes sampled from headwater and middle reach streams on Fort Riley Military Reservation, Kansas, is available in ESA's Electronic Data Archive: *Ecological Archives* A013-008-A1.