Spatial and Temporal Trends of Deer Harvest and Deer-Vehicle Accidents in Ohio[1]

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Abstract. **White-tailed deer (*Odocoileus virginianus*) have been increasing dramatically in the eastern United States, with concomitant increases in impacts resulting from deer browsing and deer-vehicle collisions. In Ohio, the number of deer were estimated at near zero in 1940 to over 450,000 in 1995. We analyzed estimates of deer harvest and deer-vehicle collisions in 1995 for 88 counties in Ohio. These data were also related to county-level spatial data on the length of major highways, urban land, rural land, crop land, forest land, all land, and human population. The objectives of this study were to evaluate the spatial and temporal trends of white-tailed deer across Ohio and to relate these patterns to the formerly mentioned environmental and human variables. For 1995 data, positive relationships existed between the amount of urban land in the county versus the number of deer-vehicle collisions, the amount of forest land in the county versus the number of deer harvested, the human population of a county versus the number of deer-vehicle collisions, and the length of major highways in a county versus the number of deer-vehicle collisions. Negative relationships existed between the amount of crop land in a county versus the number of deer harvested, the amount of crop land versus the number of deer-vehicle collisions, and the amount of urban land versus the number of deer harvested. Nine counties, representing various levels of land-use and human population tendencies, were analyzed for historic trends in deer harvest (1985-1995) and deer-vehicle collisions (1988-1995); in each case, there were substantial rises over the previous decade. Extensions of the resulting regression lines show the possibility for continued increases in deer-vehicle collisions, especially those with a high human population and forest cover. The dramatic increases in deer populations can be attributed to increasing forest land in the state, more habitat of shrubby land, few predators, mild winters, and the deer's ability to adapt to human-inhabited environments.**

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INTRODUCTION

Deer overabundance is one of the most challenging problems facing wildlife and land managers across the United States today (Alverson and others 1988; Healy and others 1997; Warren 1997; McShea and others 1997; Stromayer and Warren 1997). Most people have long considered the white-tailed deer (*Odocoileus virginianus*) to be a highly desired wildlife resource, so that society has had a difficult time accepting the fact that deer are increasingly becoming detrimental in many areas. Marchinton (1997) summed up the primary obstacle to deer management with the term urbanism. By urbanism, he states that "...we have a public that seems to be developing a very unnatural relationship with nature." Thus, the opinions and views of some people contrast with a healthy and sustaining ecosystem.

Before European colonists in the pre-1700s settled Ohio, land was not ideal for deer. The forests were too dense, and covered over 95% of the state (Griffith and others 1993). With dense forest canopy, the shrubs and other low vegetation within the 'deer molar zone' did not grow well. These shrubs were the deer's main food and, without that necessity, deer did not flourish and their population was minimal. The settling of Ohio in the early 1800s expanded the deer population as the settlers cleared more and more of the forested land and growth of the low, deer-accessible vegetation increased. The settlers also killed many of the deer's predators. The combination of these factors led to a rise of deer population for a time.

However, in the later 1800s and early 1900s, deer were practically extirpated from the state, due to habitat loss and unrestricted exploitation. In the 1920s, deer started immigrating from Pennsylvania and Michigan into Ohio. The population went from being nearly extirpated, to an estimated 550,000 for the fall of 1996 (Fig. 1, ODNR 1996). This great increase can be credited to better habitat and improved deer harvest and population management. The white-tailed deer now thrives in Ohio

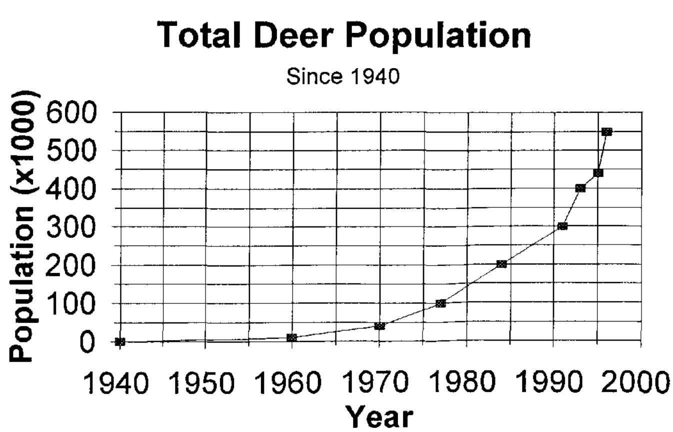

Figure 1. Estimated trends in deer populations in Ohio, 1940-1996.

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as a result of suitable cover, abundant natural and cultivated foods, mild winters, and being able to adapt to human-dominated areas.

The population of deer present today is related to two primary problems for society, an increasing human competition for critical elements of deer habitat/land area, and the fundamental issue of human population growth associated with increasing road densities. Many studies have shown that deer browsing affects forest regeneration in Pennsylvania (Marquis 1975; Whitney 1984), Illinois (Strole and Anderson 1992), Michigan (Frelich and Lorimer 1985), and Ohio (Boerner and Brinkman 1996). There is also evidence for deer browsing to substantially affect the abundance and diversity of herbaceous species. Herbaceous species provide the bulk of deer summer diet (87%, McCaffery and others 1974). Rare species, especially orchids and other monocots, have been shown to be further endangered by deer (Miller and others 1992). Although deer impacts on forest communities in Ohio are probably not as problematic as in some places such as the Allegheny National Forest in Pennsylvania, there are likely more impacts in Ohio than previously realized. It is also likely that substantial damage to farmer's crop yields occurs in some places during certain times.

A second major problem associated with the overpopulation of deer is deer-vehicle accidents. Across the United States, Romin and Bissonette (1996) estimated over 538,000 deer were killed by vehicles in 1991. These accidents cost over a billion dollars in damages plus the enormous societal loss due to fatalities and injuries. In Ohio between 1989 and 1994, 17 deaths and 6,506 personal injuries resulted from approximately 128,000 deer-vehicle accidents (Tonkovich 1995). Most deer-vehicle accidents in Ohio occur during the peak of the deer-breeding season, the period of October to December,

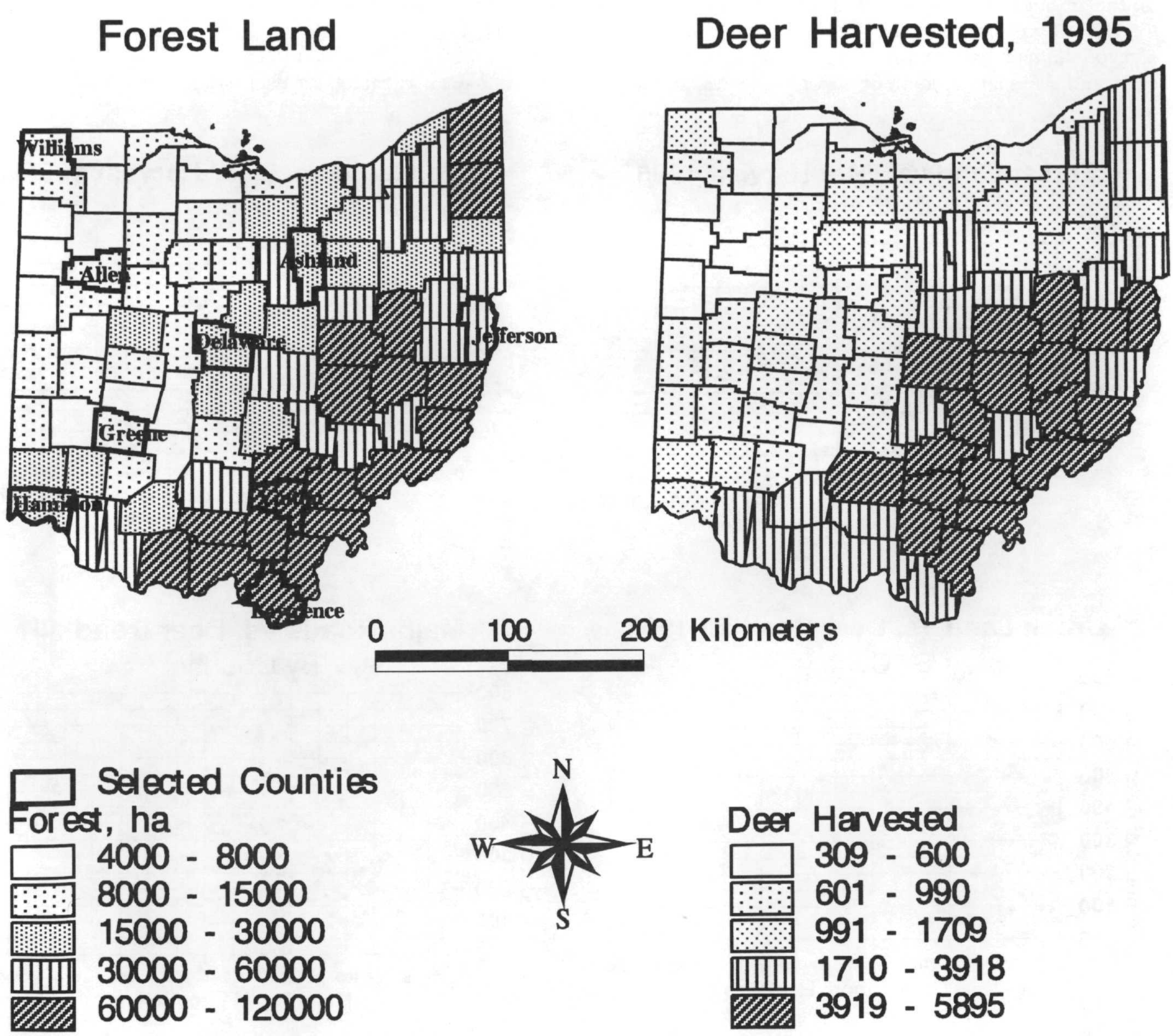

FIGURE 2. Map of Ohio (a) forest land and (b) deer harvested in 1995, by county.

also known as "the rut." During this time, deer are highly focused on breeding and the mate-seeking bucks tend to be less concerned about vehicular traffic. November is the single month with the most deer accidents. Most deer are also struck by vehicles around the hours of dusk and dawn, with 58% occurring between 5:00 PM and midnight on rural state and county roads (Wisse 1997a).

The objectives of this study were to evaluate the spatial and temporal trends of white-tailed deer across Ohio and to relate these patterns to environmental and human variables.

MATERIALS AND METHODS

Historic records on deer harvest and deer-vehicle accidents were acquired from the Ohio Departments of Transportation and Natural Resources, and the State Highway Patrol. Data included deer harvest by county for 1985-1995 (ODNR 1996), data on deer-vehicle accidents from 1988-1995 (Baker 1996), and the estimated deer populations since 1940. County-level information on the amount of forest was from the 1991 inventory of the USDA Forest Service (Griffith and others 1993), while data on human population (1990 census), urban land, crop land, rural land, length of major highways, and total land in the county were extracted from the ArcUSA data sets (ESRI 1992).

First, data were analyzed to assess relationships among county-level variables. These analyses were done via correlation analysis and stepwise regression analysis. Maps were created in ArcView (ESRI 1996) for selected variables to visually display spatial trends. Second, to assess trends in harvest and collisions, nine counties were selected which represent various levels of forest, human population, and deer densities: Allen, Greene, Williams, Hamilton, Ashland, Vinton, Jefferson, Lawrence, and Delaware (Fig. 2). From these counties, trends were evaluated via linear regression to assess the rate of increase in deer harvested (1985-1995) and deer-vehicle collisions (1988-1995). Extrapolation of the regression lines provides some capability for prediction beyond the period of evaluation, assuming historical trends continue.

RESULTS

Spatial Relationships

Table 1 shows the primary data of deer harvest and deer-vehicle collisions (1995) along with several environmental variables for each county. Analysis of the

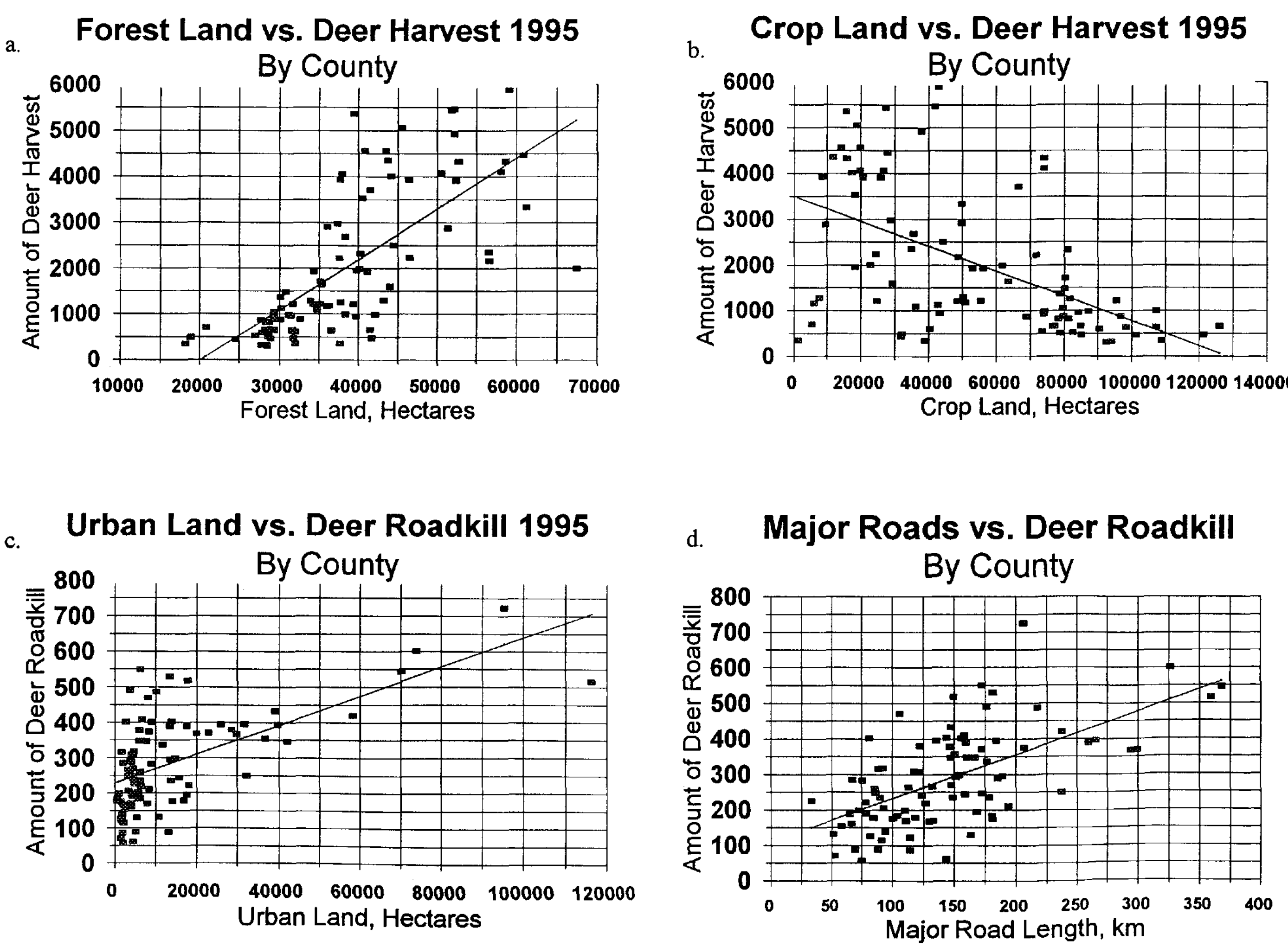

FIGURE 3. Relationships among county-level variables: (a) forest land versus deer harvested; (b) crop land versus deer harvested; (c) urban land versus deer-vehicle collisions; (d) length of major roads versus deer-vehicle collisions.

TABLE 1

County-level statistics for deer harvest, collisions, forest land, road length, urban land, human population, and crop land.

County	Harvested 1995	Roadkill 1995	Tot. Roadkill 1988-95	Average 1988-95	Forest Land, Ha	Major Rds, Km	County Land, Ha	Rural Land, Ha	Urban Land, Ha	Pop. 1990	Crop Land, Ha
Adams	2170	175	1609	187	74,894	181	152,250	150,645	1,605	25,371	48,948
Allen	543	179	1446	168	9,838	118	105,680	88,771	16,909	109,755	73,639
Ashland	1934	293	2346	273	27,325	152	109,815	105,898	3,917	47,507	56,117
Ashtabula	3336	369	2920	340	60,788	300	181,299	161,221	20,078	99,821	49,831
Athens	4327	402	2708	316	78,319	156	130,344	127,583	2,761	59,549	15,808
Auglaize	513	162	1384	161	9,938	67	103,600	99,464	4,136	44,585	78,755
Belmont	3918	244	2058	240	69,819	159	138,305	122,507	15,799	71,074	26,027
Brown	1984	236	1657	193	32,463	178	126,909	121,791	5,119	34,966	61,818
Butler	1186	433	3119	363	23,056	147	121,807	82,772	39,035	291,479	50,863
Carroll	2976	202	1534	179	46,150		101,010	95,344	5,666	26,521	28,838
Champaign	1374	206	1928	225	9,313	93	111,887	108,452	3,435	36,019	78,686
Clark	869	298	2521	294	6,913	154	103,171	88,353	14,818	147,548	69,239
Clermont	2685	395	3078	359	34,375	135	117,747	91,625	26,122	150,187	35,551
Clinton	878	270	1729	201	11,163	148	106,384	101,824	4,560	35,415	79,841
Columbia	2512	337	2491	290	39,650	177	138,114	126,358	11,757	108,276	44,338
Coshocton	5467	318	2355	274	62,200	92	145,557	140,799	4,758	35,427	42,005
Crawford	815	191	1192	139	10,813	79	104,605	100,277	4,328	47,870	81,334
Cuyahoga	349	516	2890	337	31,563	359	118,103	1,683	116,420	1,412,140	1,189
Darke	655	198	1672	195	10,344	110	156,673	152,531	4,142	53,619	126,073
Defiance	928	263	2084	243	11,056	113	106,707	102,801	3,906	39,350	74,069
Delaware	1646	550	3619	422	22,725	172	115,179	108,846	6,333	66,929	63,613
Erie	486	195	1557	181	10,413	168	68,376	50,688	17,688	76,779	32,255
Fairfield	2218	470	2818	328	18,744	106	130,197	122,038	8,159	103,461	71,878
Fayette	600	168	1301	152	5,975	130	105,153	103,052	2,102	27,466	90,587
Franklin	951	545	4458	519	18,038	368	139,341	69,110	70,231	961,437	43,312
Fulton	527	170	1286	150	6,013	133	105,337	101,312	4,025	38,498	82,609
Gallia	5060	316	2109	246	60,350	89	121,988	120,285	1,704	30,954	18,968
Geauga	1949	380	2594	302	53,219	122	105,412	76,745	28,668	81,129	18,263
Greene	879	403	2955	344	9,906	144	107,484	93,605	13,880	136,731	68,807
Guernsey	5443	347	2417	282	71,250	147	133,401	125,712	7,689	39,024	27,533
Hamilton	1279	602	2819	328	29,181	326	107,356	33,555	73,801	866,228	7,591
Hancock	643	247	2201	256	9,150	173	137,396	132,738	4,658	65,536	107,294
Hardin	881	139	1277	149	8,475	94	120,952	119,178	1,775	31,111	96,856
Harrison	4564	184	1429	166	56,781	104	103,859	97,645	6,214	16,085	20,106
Henry	309	88	955	111	5,388	70	107,743	102,564	5,180	29,108	92,590
Highland	2328	348	2470	288	16,656	160	142,190	136,186	6,005	35,728	81,275

TABLE 1 (*Cont.*)

County-level statistics for deer harvest, collisions, forest land, road length, urban land, human population, and crop land.

County	Harvested 1995	Roadkill 1995	Tot. Roadkill 1988-95	Average 1988-95	Forest Land, Ha	Major Rds, Km	County Land, Ha	Rural Land, Ha	Urban Land, Ha	Pop. 1990	Crop Land, Ha
Hocking	4358	285	1915	223	65,181	68	108,877	106,735	2,142	25,533	11,693
Holmes	2908	249	2061	240	33,869	86	109,466	106,172	3,294	32,849	49,887
Huron	1261	130	120	14	22,606	163	128,278	122,943	5,335	56,240	81,710
Jackson	4013	307	2216	258	67,456	122	108,520	104,019	4,502	30,230	17,470
Jefferson	5365	222	1753	204	52,094	78	106,428	88,200	18,229	80,298	15,728
Knox	3707	409	3162	368	28,988	158	137,528	130,781	6,747	47,473	66,520
Lake	702	356	2308	269	22,788	150	59,829	23,115	36,713	215,499	5,288
Lawrence	2884	176	1261	147	87,475	100	118,047	103,957	14,090	61,834	9,447
Licking	4112	389	3779	440	54,731	259	177,673	164,212	13,461	128,300	74,213
Logan	1709	402	3181	371	19,894	81	119,139	110,043	9,096	42,310	80,284
Lorain	1211	348	2728	318	29,781	167	128,204	86,064	42,141	271,126	48,645
Lucas	437	250	2016	235	8,906	237	88,837	56,596	32,240	462,361	31,938
Madison	639	122	1196	139	5,500	114	120,022	118,304	1,718	37,068	98,294
Mahoning	1212	396	2943	343	27,281	266	107,484	75,787	31,697	264,806	24,870
Marion	659	169	1401	163	8,106	111	104,894	96,984	7,910	64,274	85,006
Medina	1094	371	2556	298	29,463	172	109,727	86,674	23,053	122,354	36,223
Meigs	4559	155	1286	150	62,963	58	112,882	110,454	2,428	22,987	14,304
Mercer	468	115	1076	125	4,594	91	114,995	112,776	2,220	39,443	101,338
Miami	652	283	2418	282	11,019	76	105,412	96,326	9,087	93,182	76,636
Monroe	4075	62	471	55	84,244	144	118,103	113,615	4,488	15,497	19,800
Montgomery	604	420	2701	315	7,600	237	118,880	60,629	58,252	573,809	40,409
Morgan	3532	178	993	116	52,663	85	108,779	108,263	516	14,194	18,394
Morrow	1215	260	1899	221	21,375	86	104,296	98,043	6,253	27,749	55,493
Muskingum	5895	530	3410	397	62,494	181	168,608	155,165	13,443	82,068	42,939
Noble	3920	188	668	78	45,463	65	103,082	102,311	771	11,336	20,734
Ottawa	346	132	1070	125	4,463	51	65,598	54,860	10,738	40,029	39,074
Paulding	466	71	689	80	7,894	53	108,002	106,315	1,688	20,488	85,239
Perry	4061	309	1890	220	44,700	118	105,970	101,782	4,188	31,557	26,876
Pickaway	1225	234	1856	216	10,663	90	130,535	124,218	6,318	48,255	95,501
Pike	2232	199	1543	180	71,356	73	114,736	113,618	1,119	24,249	24,637
Portage	1601	487	3188	371	45,500	218	128,204	118,050	10,154	142,585	29,428
Preble	982	219	1770	206	14,556	127	110,592	104,107	6,486	40,113	74,315
Putnam	349	57	301	35	6,713	75	125,873	123,754	2,119	33,819	108,947
Richland	1917	518	3792	442	34,850	150	128,463	110,621	17,843	126,137	52,961
Ross	4338	491	3524	411	55,156	176	177,797	174,085	3,713	69,330	74,126
Sandusky	663	183	1673	195	7,913	181	105,930	100,116	5,814	61,963	77,168

TABLE 1 (*Cont.*)

County-level statistics for deer harvest, collisions, forest land, road length, urban land, human population, and crop land.

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Scioto	1995	235	1723	201	110,563	149	157,471	143,675	13,797	80,327	22,884
Seneca	992	241	1739	203	10,250	124	142,664	138,001	4,663	59,733	107,321
Shelby	815	225	1177	137	7,031	33	105,676	100,832	4,844	44,915	78,402
Stark	1303	394	2767	322	22,606	184	149,183	109,445	39,739	367,585	50,204
Summit	1164	724	4655	542	35,125	206	104,894	9,413	95,482	514,990	6,001
Trumbull	2353	367	2561	298	62,256	294	158,116	128,317	29,799	227,813	35,039
Tuscarawas	4925	378	2991	348	61,150	146	147,370	141,319	6,051	84,090	37,960
Union	957	267	1981	231	13,138	132	112,405	109,043	3,363	31,969	84,394
Van Wert	325	87	838	98	4,488	114	105,833	103,855	1,978	30,464	94,026
Vinton	3927	88	669	78	78,769	88	106,312	93,236	13,076	11,098	8,552
Warren	1129	389	2923	341	18,463	160	104,544	86,816	17,728	113,909	42,731
Washington	4461	375	2714	316	78,169	207	166,018	157,657	8,361	62,254	28,002
Wayne	990	295	2342	273	24,238	189	145,298	131,763	13,536	101,461	87,309
Williams	1478	289	2305	269	13,619	186	108,769	104,670	4,099	36,956	80,222
Wood	476	211	1865	217	6,119	194	160,320	151,992	8,328	113,269	121,353
Wyandot	1051	127	1092	127	11,675	82	104,807	103,333	1,474	22,254	79,643
Totals	178,889	27,198	184,142	243.8	624,378	12,579	10,600,701	9,347,019	1,253,707	10,847,115	4,826,086

correlation matrix and resulting graphs show a number of significant relationships (Table 2). Assuming a direct relationship between deer population and deer harvest, we see a strong relationship between land-cover and the

TABLE 2

Correlation matrix of environmental variables and deer harvested/accidents.

	Harvested	Accidents 1995	Accidents 1988-95	Forest area	Road length	County area	Rural area	Urban area	Human pop.	Crop area
Harvested	1.00									
Accidents, 1995	0.10	1.00								
Accidents, 1988-95	0.16	0.54*	1.00							
Forest area	0.80*	0.15	0.11	1.00						
Road length	-0.07	0.61*	0.60*	0.09	1.00					
County area	0.37*	0.28**	0.36*	0.38*	0.38*	1.00				
Rural area	0.41*	-0.19	-0.07	0.30**	-0.16	0.76*	1.00			
Urban area	-0.21	0.61*	0.52*	-0.03	0.67*	-0.04	-0.68*	1.00		
Human pop.	-0.24	0.28**	0.45*	-0.09	0.72*	0.01	-0.59*	0.93*	1.00	
Crop area	-0.54*	-0.35**	-0.23	-0.70*	-0.22	0.18	0.40*	-0.41*	-0.31**	1.00

*p <0.001 **p <0.01

number of deer in a county. Forest land in the county (Fig. 3a) is positively correlated ($r = 0.80$), while crop land in the county (Fig. 3b) is negatively correlated ($r = 0.54$) with the number of deer harvested in 1995. The maps of forest and deer harvest (Fig. 2) show relatively similar patterns where the highly forested regions in the southeast are also the locations of large deer harvest, and the high crop land/low forest land regions of the northwest show the opposite. Other variables significantly ($p < 0.01$) related to deer harvest included county land ($r = 0.37$) and rural land ($r = 0.41$) (Table 2). A stepwise regression using county deer harvest (1995) as the response variable yielded the following regression equation with a multiple r^2 of 0.76 ($n = 88$, $p < 0.001$):

$$\text{Deer Harvested} = 329.32 + 0.0377\ (\text{Rural land}) - 0.0171\ (\text{Crop land})$$

When calculated on a density basis, to account for the variation in county size, the equation was also significant with a multiple r^2 of 0.78 ($n = 88$, $p < 0.001$):

$$\text{Deer Harvest per 100 ha} = 4.61 - 0.44\ (\%\ \text{Crop}) - 0.30\ (\%\ \text{Urban}) - 498.85\ (\text{km road/ha})$$

No apparent relationship was found between deer harvest and deer-vehicle accidents or deer harvest and length of roads in the county in 1995, even though Tonkovich (1995) found a significant correlation between deer-vehicle accidents and buck-gun harvest per square mile for the 1989-1994 period.

For deer-vehicle collisions in 1995, the major related variables included the amount of urban land in the county (Fig. 3c) and the cumulative length of major highways in the county (Fig. 3d), both of which were positive ($r = 0.61$). When viewed on Ohio maps, the amount of urban land shows that the counties largely occupied by metropolitan areas also tend to show the greatest number of deer-vehicle collisions (Fig. 4). Other significant, but less related variables to collisions included human population ($r = 0.28$), county area ($r = 0.28$), and the amount of crop land in the county (-0.35). There was no apparent relationship between deer-vehicle accidents and forest area or rural area. A stepwise regression using county deer-vehicle accidents in 1995 as the response variable yielded the following regression equation with a multiple r^2 of 0.51 ($n = 88$, $p < 0.001$):

$$\text{Accidents} = 53.02 + 0.383\ (\text{Road length}) + 0.0015\ (\text{County land}) + 0.0028\ (\text{Urban land}) - 0.0003\ (\text{Crop land})$$

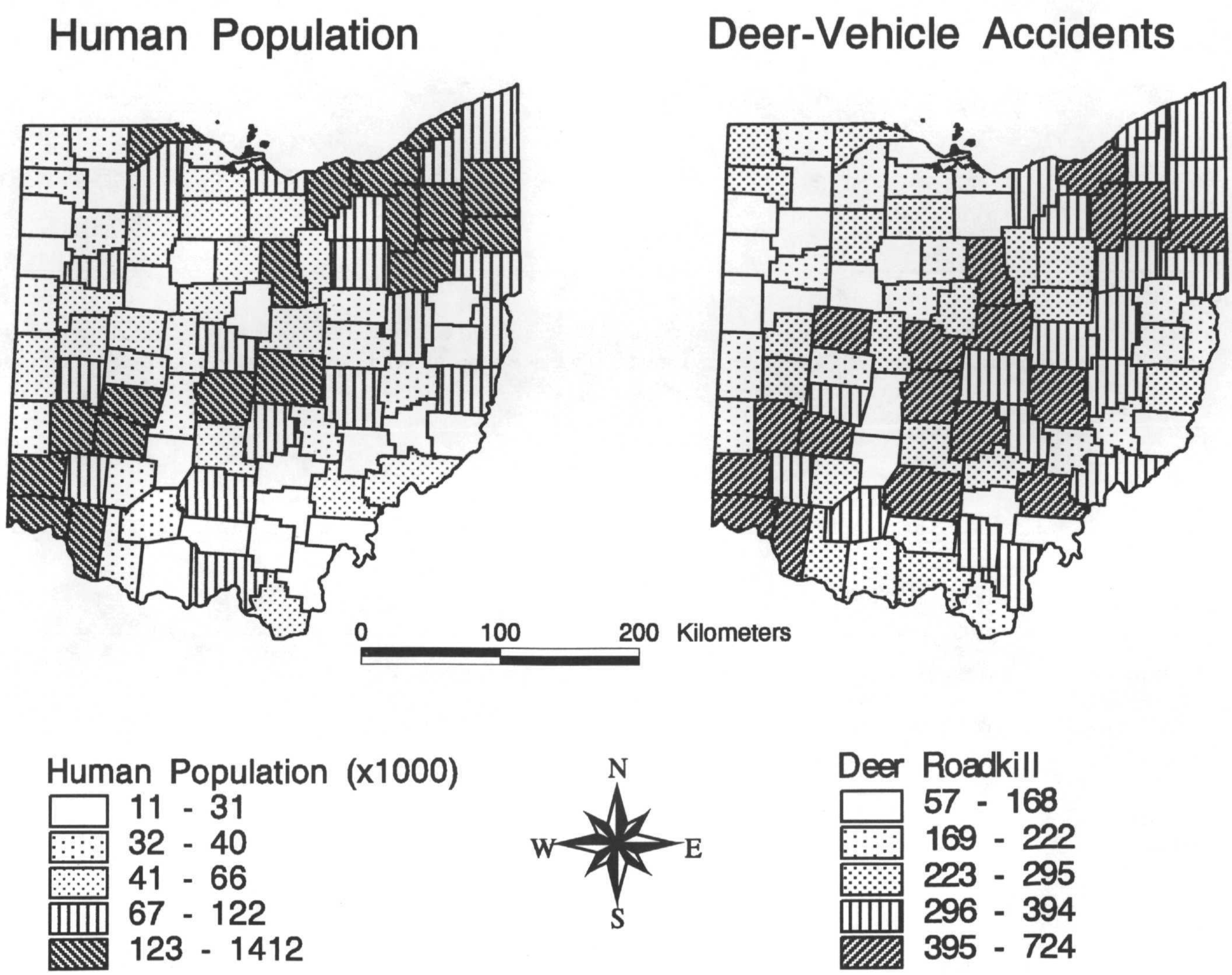

FIGURE 4. Map of Ohio (a) human population density and (2) deer-vehicle collisions in 1995, by county.

When calculated on a density basis, the multiple r^2 improved to 0.59 ($n = 88$, $p < 0.001$) with the following equation:

Accidents per 100 ha = 0.52 - 0.0042 (% Crop) - 0.0044 (% Forest) + 0.0019 (% Urban)

Temporal Trends

From the nine selected counties, we found that both the amount of deer harvested and the deer-vehicle collisions in the county increased substantially through the study period. For deer harvest, all counties showed increases from 1985-1995, ranging from an average of 48 more deer harvested per year (averaged for the 11 years) for Allen County to 92 additional deer harvested each year in Delaware County (Fig. 5) to 345 additional deer per year for Jefferson County. There was an average increase of 150 deer harvested per county per year for the 9-county area over the 11-year period (Table 3). The counties with the largest increases in deer harvest (Jefferson, Vinton, and Lawrence) also have the highest amount of forest land among the nine counties (Fig. 2, Table 3). The total number of deer harvested in this period for these nine counties increased by nearly 15,000, or over 4-fold. Over the entire state, total deer harvest increased from 64,263 in the 1985-86 season to 179,543 in the 1995-96 season, a 179% increase (ODNR 1996). Only 59,812 deer were harvested in 1983-84, 7,594 in 1973-74, and 2,074 in 1963-64.

If the regression lines were extended into the future so that we assume the same rate of growth as occurred in the previous decade, estimates of deer harvest for 2000 and 2005 could be made (Table 3). These numbers are extremely high, unbelievably so. Increases, on average, would be predicted to be up 36 and 72%, respectively, for the 2000-01 and 2005-06 seasons compared to the 1995-96 season (Table 3). Indeed, subsequent data from the Ohio Department of Natural Resources show that 1995-96 was the peak year on record, and the harvests for 1996-1998 were less than 1995. Since 1995-96, the harvests were 158,000 in 1996-97, 153,159 in 1997-98, and an estimated 115,000 in the 1998-99 (Tonkovich, personal communication). Harvest estimates resulting from linear extrapolations of the trend lines could not be sustained by the deer populations. Apparently the deer herd in Ohio is beginning to stabilize.

For deer-vehicle collisions, an increase was also noticed for each of the nine counties for the period 1988-1995 (Table 4). The most extreme example is Hamilton County (location of Cincinnati), with the highest human population and length of highways of the nine representative counties, which had a deer-vehicle accident increase that averaged 73 more accidents per year between 1988 and 1995. Delaware County, graphed in Fig. 5, also recorded an increase of an average of 30 additional accidents per year during that period. Many of the lesser-populated counties also had increases, but not nearly at the rate of Hamilton County (Table 4).

Again, by assuming a linear increase into the future by extrapolation of the regression lines, we see potentially very high levels of deer-vehicle collisions. However, deer-vehicle accidents have also appeared to stabilize for 1996-1998 at between 24,000 and 25,000, a period when hunting was intentionally high (Wisse 1997a; Tonkovich, personal communication). We predicted, on average for the 9 counties, a potential overall increase of 24% in 5 years (Table 4); fortunately, this increase will not occur based on data obtained for 1996-1998. Of course, if the deer herd is allowed to grow again along with concomitant increases in traffic volume, the trend will likely move up again.

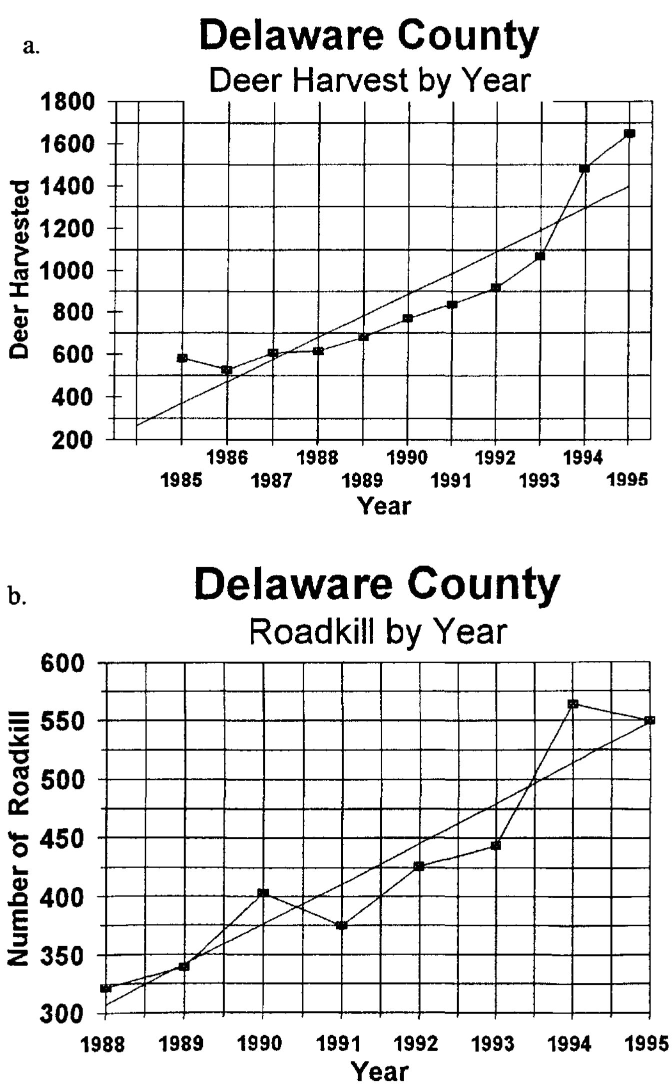

FIGURE 5. Trends in (a) deer harvested, 1985-1995 and (b) deer-vehicle collisions, 1988-1995 for Delaware County, OH.

DISCUSSION

The number of deer harvested in 1995 was highly correlated with the amount of forest in Ohio counties (Figs. 2,3). It is clear that the white-tailed deer is primarily a forest species. The best habitat for them consists of older forest stands for shelter and younger stands or old field vegetation for an ample supply of browse (deCalesta and Stout 1997; Waller and Alverson 1997). The negative relationship between deer harvest and the amount of crop land in the county implies less suitable habitat in those areas, even though the extensive availability of corn in the fall tends to produce

TABLE 3

Deer harvest for selected counties, 1985-1995.

County	1985	1995	Yrs	Inc./ year	Est. 2000	Est. 2005	% Increase 2000	% Increase 2005	Forest, thous. ha
Jefferson	1400	5200	11	345	6927	8655	33	66	52
Vinton	900	3850	11	268	5191	6532	35	70	79
Lawrence	200	2840	11	240	4040	5240	42	85	87
Ashland	700	1850	11	105	2373	2895	28	57	27
Williams	675	1570	11	81	1977	2384	26	52	14
Delaware	390	1400	11	92	1859	2318	33	66	22
Hamilton	85	1090	11	91	1547	2004	42	84	29
Greene	25	905	11	80	1305	1705	44	88	10
Allen	75	605	11	48	846	1087	40	80	10
Total/Average	4450	19310		150	26065	32819	36	72	37

well-fed deer in those counties. The food supply and shelter in those counties can be limiting, however, for much of the year. In Ohio, about two-thirds of the deer herd are found in the state's hill country, the eastern and southeastern counties (ODNR 1997a). These regions give the best year-round habitat and food supply.

It is apparent that the deer herd in Ohio was extremely dense in 1995, more so than any time in known history. Deer thrive in the presence of suitable cover, abundant natural and cultivated foods, mild winters, and through their adaptability to human-dominated landscapes. As such, the white-tailed deer can now be considered a keystone species of Ohio (Waller and Alverson 1997). By keystone, we mean that deer, in many places of Ohio, substantially alter the ecological communities in which they live by (1) affecting the distribution or abundance of many other species or (2) affecting community structure by modifying patterns of relative abundance among competing species. Examples of these types of impacts on vegetation, in the Midwest, are mentioned in the introduction and other examples are plentiful in the book edited by McShea and others (1997). Besides impacts on vegetation, high deer densities impact other wildlife resources. For example, deCalesta (1994) found that intermediate-nesting birds declined 37% in abundance and 27% in diversity when deer densities were high.

The hunting community in general does not always

TABLE 4

Deer-vehicle accidents for selected counties, 1988-1995.

County	1988	1995	Yrs	Inc./ year	Est. 2000	Est. 2005	% Increase 2000	% Increase 2005	Humans thous.	Hwys. km
Hamilton	25	605	8	73	968	1330	60	120	866	326
Delaware	310	550	8	30	700	850	27	55	67	172
Greene	250	475	8	28	616	756	30	59	137	144
Ashland	244	308	8	8	348	388	13	26	48	152
Williams	240	305	8	8	346	386	13	27	37	186
Jefferson	178	241	8	8	280	320	16	33	80	78
Lawrence	102	188	8	11	242	296	29	57	62	100
Allen	160	178	8	2	189	201	6	13	110	118
Vinton	57	96	8	5	120	145	25	51	11	88
Total/Average	1566	2946		19	3809	4671	24	49	158	152

agree that high deer populations are problematic. Diefenbach and others (1997) analyzed 13 years of white-tailed deer data for Pennsylvania to compare trends in deer populations to the opinions of hunters on deer management. The majority of hunters disagreed that damage to Pennsylvania forests by deer was a problem or that deer caused serious conflicts with other land uses. In a public attitude survey of Ohio hunters, deer damage was considered an 'annoyance,' rather than a major problem (ODNR 1998). Stoll and others (1991) reported that optimum deer herd sizes are set for each county based on formulas for farmer tolerances to crop damage or deer-vehicle accidents, whichever is lower.

The high herd densities have also begun to take their toll on the herd itself, as the condition of the herd, especially in the hill counties, has been shown to decline (Stoll and Parker 1986; Tonkovich 1996; ODNR 1997b; Tonkovich, personal communication). Researchers report statistically significant decreases in field-dressed weight between 1982 and 1996 for does (4 pounds less) and bucks (10-12 pounds less). Declines in antler beam diameters are also apparent for deer taken from the hill country during this 5-year period.

We found a positive relationship between deer-vehicle collisions and both the human population and the total length of major highways in the county (Figs. 3,4). Obviously, there are more opportunities for collisions with more traffic on more highway miles. If the county has both high amounts of forest (for example, high deer densities) and high human population densities, the risk of a deer-vehicle collision in higher; this is apparently the case for Hamilton County. Based on our data, it is clear that the number of accidents is more related to human factors (for example, road lengths, urban land, human populations) than to deer- or habitat-related factors (for example, harvested deer, forest land, cropland).

In Ohio alone, an estimated 27,200 accidents were reported for 1995. Romin and Bissonette (1996) estimated over 538,000 deer were killed by vehicles in the United States in 1991. An estimated one million vertebrates are killed each day on US roads (Lalo 1987). The economic effects of deer collisions are enormous. Injuries and loss of human life also occur at some of these accidents, especially when the driver tries to avoid a deer collision and collides with another car or object. As the number of motorists increase, and as the deer herd increases, so will the deer-vehicle collisions. Thus, county and state planners and regulators have an opportunity/responsibility to address high road densities, land-use designations, and the like, to mitigate for the expected increase in collisions.

There is some research showing that various structures can be used to help control road crossing of deer. Nine foot fencing along roads, planting grass along side the road to help the deer to resist crossing, and reflectors along roadsides have all been used (Forman 1995). These methods have been more successfully used in Europe, but more research is needed relative to the overpopulation of deer in this country (Romin and Bissonette 1996).

To also help reduce the urban deer overpopulation problem, five urban deer zones have been set up in Ohio. In these zones, a hunter may hunt in a human inhabited area, and they may each kill up to 5 or 6 deer throughout the deer season. The intention is to lower the deer population in those heavily-traveled zones which would reduce the chance of hitting a deer (as well as reduce the overgrazing problem common in parks, flower gardens, and so forth). This strategy appears to be effective in reducing the urban deer population (Tonkovich 1998).

We have shown that the deer population has been rising in Ohio since 1940, and especially so during the 1985-1995 study period (Figs. 1,5). Evidence now exists that the population peaked in 1995, and has stabilized somewhat, but is still very high. The extremely rapid rise in the deer population can be attributed to several factors. The amount of forest land in Ohio has been increasing since about 1940 (Griffith and others 1993); thus, forest habitat has also increased, especially young forests with ample food supplies. In addition, there are relatively mild winters in Ohio (especially since the 1980s), there has been ample food and shelter, and the deer's predators are presently very scarce.

Data for recent years have shown that the Ohio deer herd is being contained at a population level between 400,000-450,000 (Tonkovich, personal communication). If the Ohio deer herd were allowed to grow unchecked, serious impacts could result. One major impact would be a continued increase in vegetation damage from deer scavenging for food in urban, agricultural, and forest areas. Increased deer-vehicle accidents would also occur, as we have predicted. The increases in deer would eventually level off as the carrying capacity of Ohio landscapes is reached. Deer herd decline would then become even more problematic, resulting in starvation and disease when winter conditions are limiting.

Because the natural predators for deer are largely gone, humans must do the management. It may be possible, but not very likely at this time, to reintroduce or enhance the population of native predators as a management technique to help reduce the rapid rise of the deer herd. However, of all management tools available, hunting is currently the most effective. In the future, however, new paradigms in land-use planning may provide effective management tools. The Ohio Division of Wildlife carefully sets hunting policy each year to regulate the deer herd. Controlling the deer population is not the only thing hunting does. It is a great boost to Ohio's economy as well. According to a 1996 National Survey of Fishing, Hunting and Wildlife-Associated Recreation, hunters of all types spent a total of $515 million in Ohio on hunting-related expenditures (Wisse 1997b). Expenses included travel, food, lodging, equipment, and clothing purchased by the hunters.

The deer herd in Ohio, up until the last couple of years, has expanded very rapidly since 1940 and has become a serious problem with vegetation damage and vehicle accidents. For the sake of both humans and deer, we must work together to support efforts to control deer herd growth and reduce deer-vehicle accidents.

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