A Call for Evaluation of the Role of Regional-Scale Environmental Toxicity In Population Declines of Northern Bobwhite Quail

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The disappearance of the Northern Bobwhite quail from much of its regional range in the eastern United States over the past six decades has been a major ecological, aesthetic and recreational loss for the region. Many land management practices that can affect quail habitat distribution and quality have doubtlessly played an important role in the loss of quail from its original range. However, the current absence of quail from even high quality habitat within its normal range suggests that there are other critical factors that should be examined to provide the integrative understanding of multifactor stress abatement that will ultimately be required to restore this valuable species to its native range. These include several toxic compounds derived from fossil fuel combustion and other industrial processes that produce organic chemicals that adversely affect biological processes. Among the emissions from fossil fuel combustion are acidic compounds derived from sulfur (S) and nitrogen (N) as well as toxic trace metals such as mercury (Hg) and lead (Pb). In addition, regional use of agrochemicals and fluorocarbons from industrial processes have produced multiple compounds with a strong potential to enter and disrupt avian food chains.

We believe the unexplained decline of quail across its broad range is a signal, a critical challenge, and an opportunity to identify the principal interacting stressors that are now adversely affecting the health of a broader range of terrestrial ecosystems and resident populations, including humans. This challenge comes at a time when there are alarming indications that there have been other significant regional declines in several components of our terrestrial ecosystems, notably insect populations (Wagner, 2020) and other bird species (Evers et al., 2012). Human health has also been a component of our terrestrial ecosystem for which pollution has been estimated to be responsible for 9 million premature deaths per year (Fuller et al. 2022). More than ever, defining the role of interacting stresses in driving biological responses is important for broader understanding of ecosystem health.

The quail's broad native range, its iconic importance as an aesthetic fixture in rural culture, and its strong support from the hunting and sporting dog training community make it perhaps the most appreciated and valuable among the eastern bird species. As a ground nesting species that moves, feeds, and nests at ground level, the bobwhite receives the vertically integrated accumulation of products of both wet and dry deposition of air pollutants that occurs at ground level. The strong dependence of young chicks on the high protein content of insects increases the probability that food chain accumulation of toxicants will adversely affect them at this critical life stage. From a research logistics perspective, the existing quail breeding and pen rearing industry that currently exists to support put and take hunting, would likely be a valuable asset as a supply system for both eggs and chicks to support research opportunities. In addition, genetic research at Texas A&M University that has sequenced the quail genome (Seabury, 2014) may be critical to both future breeding and management research to improve quail resistance to environmental stresses.

To provide strong evidence of causality for observed patterns of change in quail populations within a region in which many environmental conditions have changed across space and time, it will be important to evaluate concurrent changes in factors which have also changed over similar times and spatial scales and which have a plausible mechanistic link to quail survival and health. This approach of coupling broader regional response patterns with patterns and plausible mechanistic linkages to natural and anthropogenic stresses proved valuable in linking regional declines of some tree species with patterns of anthropogenic stress from air pollutants (McLaughlin and Kohut, 1992) What we propose is a focus on a multifactor stress component analysis that considers the spatial and temporal distribution of several potential chemical stressors that have changed across the range of quail population loss over time. Among the more obvious pathways by which quail health may be affected are buildup of toxic elements in food chains (trace metals), liquid uptake of dissolved toxics and acidity in chemically enriched dew that supplies some of the water intake needs of quail, and effects of wet and dry deposition of acidity on the calcium physiology of terrestrial systems (McLaughlin and Wimmer, 1999) including insects that supply calcium used in egg formation.

We believe a careful review of census data that define the spatial and temporal scale of changes in quail populations within the region combined with changes in regional patterns of pollutant inputs would be productive. Particularly important are analyses of individual and combined interactive toxic thresholds for various toxic elements that adversely affect bird growth and physiology through food chain accumulation. Such an effort would suggest whether future focused research in these areas would be productive to further understand and improve quail populations in this region. We focus here on defining relationships among quail health and four of these potential stressors as a potentially productive beginning to defining where strong and potentially interactive effects among them may occur.

Defining and Evaluating Quail Population Declines Over Time

We have used the annual state level National Breeding Bird Survey data (USGS, 2018) to estimate population changes in quail in 5 states that covered the eastern US over both North/South (Texas to New York) and East /West (Virginia, Georgia, to Iowa) gradients. The series were developed around annual interval data that extended from 1966 or 1967 to 2019 for each state. The individual data series for each state were then normalized to express the annual data as a percentage of the average of the 5 maximum annual counts for each series. We summarized across states by then averaging the normalized decline data for each year across the five states. These annual data for each state are presented in Table 1 and Figure 1a and the 5 state average is shown in Figure 1b.

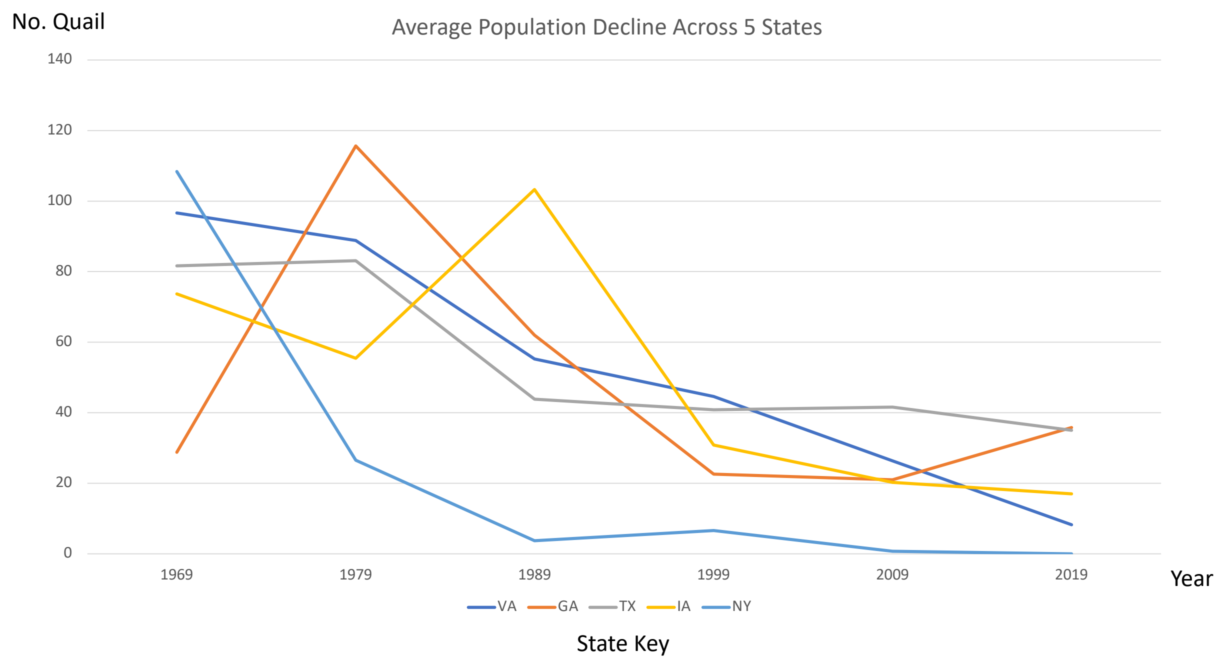
The data indicated that on average populations had declined to 50% of maximum values by 1988 and to 25% of maximum values by 1994. The strongest declines had occurred in New York and Virginia over the 1967-2019 interval.

Table 1. Annual population counts of Northern bobwhite quail for 5 states over the interval 1966-2019. Data are normalized to the maximum 5 year population values.

Annual Quail Counts as a % of the Maximum 5 Annual year Counts (1966 - 2019)						
Source (National Breeding Bird Survey , USGS						
Annual Count as % of 5 year Maximum Count						
Year	**VA**	**GA**	**TX**	**IA**	**NY**	**5 State Average**
1966	69	37			33	47
1967	83	44	25	33	81	53
1968	106	37	36	97	114	78
1969	97	29	82	74	108	78
1970	87	46	97	93	69	78
1971	95	31	69	55	108	72
1972	62	35	105	91	88	76
1973	78	43	96	84	58	72
1974	93	42	104	102	55	79
1975	90	85	90	69	63	79
1976	92	76	87	97	46	80
1977	101	91	98	111	41	89
1978	84	101	84	87	27	77
1979	89	116	83	55	27	74
1980	84	95	73	75	37	73
1981	91	88	68	85	60	78
1982	93	83	81	43	34	67
1983	101	96	74	45	41	71
1984	70	91	61	22	29	55
1985	80	64	60	33	0	47
1986	75	79	50	47	3	51
1987	68	81	72	66	8	59
1988	76	75	65	89	12	64
1989	55	62	44	103	4	54
1990	70	66	39	63	7	49
1991	58	49	43	86	1	47
1992	70	61	61	88	21	60
1993	60	46	62	42	20	46
1994	52	44	85	35	12	46
1995	71	42	55	43	21	46
1996	46	40	47	21	22	35
1997	43	34	51	24	9	32
1998	36	28	43	16	10	27
1999	45	23	41	31	7	29
2000	38	21	29	36	3	25
2001	38	24	31	11	1	21
2002	34	30	34	17	1	23
2003	26	18	45	46	9	29
2004	29	18	56	39	2	29
2005	29	18	59	35	7	30
2006	24	26	38	44	1	27
2007	26	15	44	41	1	25
2008	22	19	34	15	0	18
2009	26	21	42	20	1	22
2010	18	25	39	13	1	19
2011	13	23	25	8	1	14
2012	18	20	29	18	1	17
2013	16	32	32	26	0	21
2014	11	27	36	43	0	23
2015	12	26	54	57	1	30
2016	9	27	62	83	0	36
2017	9	27	52	75	0	33
2018	7	32	37	89	0	33
2019	8	36	35	17	0	19

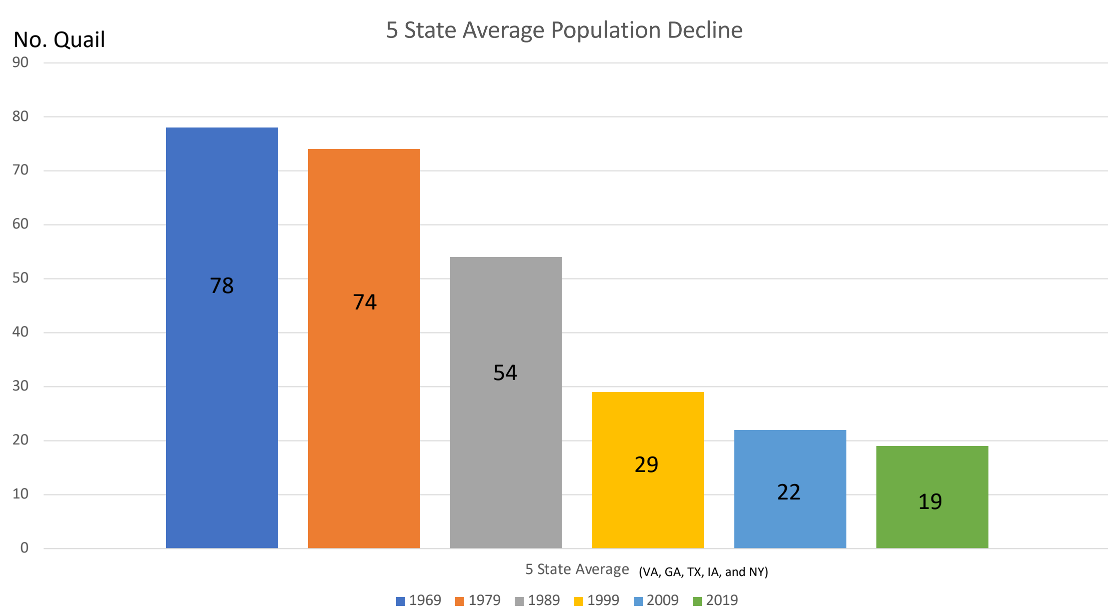
Figure 1. Rates of decline in quail populations in 5 eastern states. Data are normalized to the maximum 5-year counts for each state. Numbers represent population remaining compared to the 5-year maximum population levels for each state.

Figure 1a - Population decline trends for each of 5 states



Source - National Breeding Bird Survey, USGS

Fig. 1b. The average population decline pattern across all five states



Source - National Breeding Bird Survey, USGS

Changes in Land Use Patterns

The importance of changes in farming practices over time has long been recognized as one of the very important stresses on bobwhite quail populations and involves sizes of fields and cultivation practices in fields, conversion of cropland to planted forests, pesticide use, and introduction of diseases in pen released birds (Fies, et al.,1987 , Brennan, 1991). We certainly agree with the need to consider these many factors in reversing the quail population decline, but wanted to evaluate how consistently some macro indicators of cropping selection and intensity related to observed population decline patterns. Did changes in these patterns suggest that synchronous land use changes in the five study states were likely triggering influences for the decline or were they perhaps just contributors?

Our analyses shown in Tables 2a, 2b and 2c examined changes in average farm size (and potential field sizes), the acreage of grass based hay produced (a measure of grassland cover) and acreage in soybeans and corn produced per farm (a measure of the relative importance of intensive row cropping). Our conclusions were as follows:

1. There has been no obvious significant influence of average farm size on quail population declines during our study interval. Average farm sizes changed little over the period of quail decline so large changes in field edge areas and associated quail cover seem unlikely to have occurred during this time.

Table 2a: Total Farm Acres (M) and Average Farm Size (Av Acres)

	Georgia		Iowa		New York		Texas		Virginia	
Year	**Total**	**Average**	**Total**	**Average**	**Total**	**Average**	**Total**	**Average**	**Total**	**Average**
2021	10.2	247	30.5	359	5.9	207	125.0	510	7.7	186
2015	9.8	234	30.6	352	7.0	205	128.5	520	8.2	176
2010	9.7	219	30.6	342	7.1	197	131.6	530	7.7	186
2005	10.7	218	31.2	351	7.4	206	130.0	568	8.5	179
2000	10.9	222	32.5	346	7.6	205	130.9	573	8.7	180
1995	11.5	235	33.0	330	7.9	208	132.0	545	8.8	180
1990			33.5	325						
1985			33.6	303						
1980			33.5	325						
1975			34.8	262						

2. Quail populations have declined in two states in which grass hay production acreage has decreased (NY and Iowa) one in which it has increased (Texas) and two in which it has remained the same (VA and Georgia) since the 1950s. No consistent effect of this component of grassland cover was apparent.

Table 2b: Non Alfalfa Hay Production (K Acres)

Year	Georgia	Iowa	New York	Texas	Virginia
2020	570	330	760	4900	1106
2010	650	320	910	5100	1250
2000	650	430	1050	4200	1200
1990	570	300	1120	3800	1020
1980	460	520	1400	2540	880
1970	427	702	1377	2125	903
1960	433	1280	1957	1733	907
1950	977	2246	2319	731	1107

3. Production acreage in corn and soybeans, more intensively cultivated crops, has gone down dramatically in GA, increased sharply in New York and Texas, and remained the about the same in Iowa and Virginia during the past 50 years as quail populations declined. So, we did not see changes in the larger scale land use patterns that would have been expected to act as triggers for the observed decline in quail populations among these 5 states and regions.

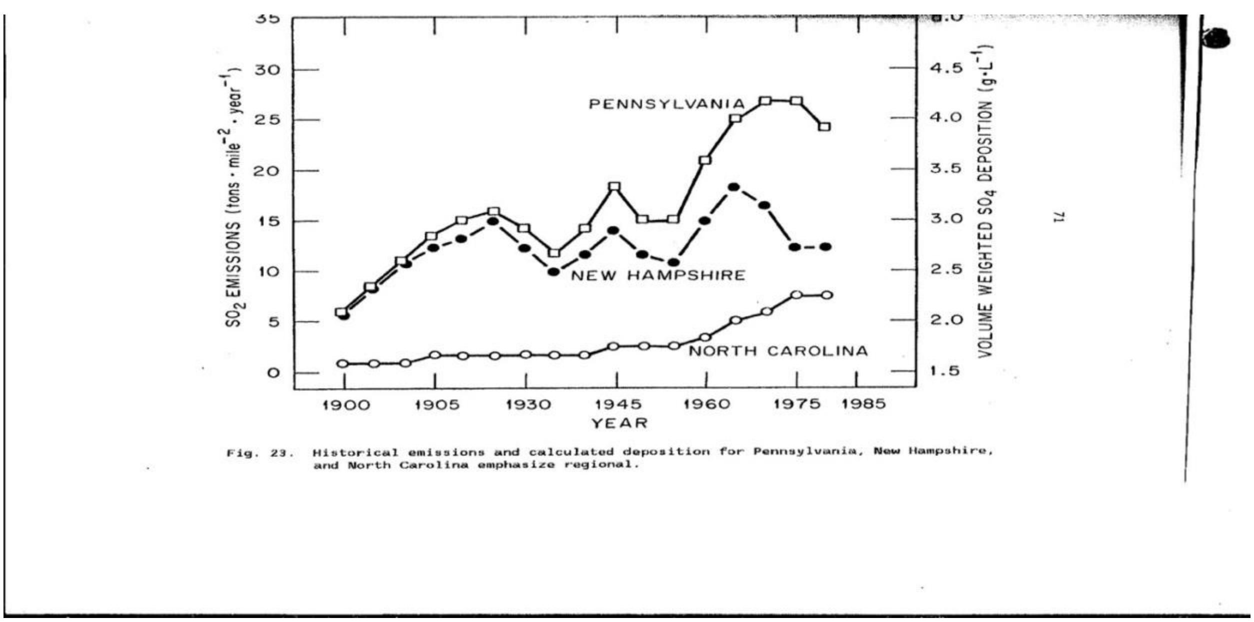
Table 2c: Corn and Soybean Production (K Acres)

Year	Georgia			Iowa			New York			Texas			Virginia		
	Corn	Soy	Total	Corn	Soy	Total	Corn	Soy	Total	Corn	Soy	Total	Corn	Soy	Total
2020	420	100	520	13600	4450	18050	1030	315	1345	2250	120	2370	540	510	1050
2010	295	270	565	13400	9800	23200	1050	280	1330	2300	205	2505	490	560	1050
2000	360	170	530	12300	10700	23000	980	135	1115	2100	290	2390	470	490	960
1990	650	900	1550	800	1210	2010	1210		1210	1650	220	1870	530	540	1070
1980	1600	2200	3800	14000	8300	22300	1350	20	1370	1500	700	2200	830	630	1460
1970	1750	490	2240	10760	5709	16469	847	6	853	670	170	840	692	372	1064
1960	2304	106	2410	12658	2615	15273	653	6	659	1391	84	1475	741	334	1075
1950	3295	78	3373	9837	1960	11797	673	9	682	2959	10	2969	973	202	1175

Atmospheric Emissions from Coal Fired Power Plants

This past century has seen dramatic increases in emissions of pollutants from use of fossil fuels both from coal combustion in large power plants and petroleum derived transportation fuels. While the level of emissions has varied by region, the dynamics of increases have been similar across larger regions (See Figure 2). The primary pollutants of interest have been sulfur and nitrogen compounds which have been shown to acidify lakes, streams, and forest soils and to reduce productivity of both forests and aquatic systems where deposition is highest. In addition to N and S, a wide variety of other hazardous pollutants including mercury, lead, and arsenic which have negative impacts on terrestrial biota are emitted in significant quantities by coal-fired power plants (See Table 3). It is important to note in Figure 2 that the most rapid increases in power plant emissions occur in the 1960 -1990 time interval when quail populations began their decline. On the other hand, our analyses (not shown here) indicate that S and N emissions for our 5 states declined by an average of about 90% from 1990 to 2019 without producing any apparent recovery in quail populations during that time. So, changes in quail populations that occurred during the period of rapidly increasing emissions were either of a more persistent nature for which a threshold was reached or are perhaps more closely influenced by other factors.

Figure 2. SO2 emissions from 3 eastern states from 1900 to 1980 show parallel trends in the timing of increases and reflect regional synchrony in industrial development over time



Atmospheric Mercury Emissions

In addition to its release from coal fired power plants (See Table 3 - EPA, 2022), mercury is released from a wide variety of industrial plants, including wastewater treatment plants, cement plants, and incinerators. Mercury has long been recognized as a highly reactive neurotoxin in humans, but recent research indicates it is accumulating in terrestrial ecosystems and is building up in insect eating birds, such as forest songbirds (Evers et al. 2012). Effects of mercury across the landscape now appear to be far more severe than originally thought including the near disappearance (45% decline in 20 years) of wood thrush from the Adirondack mountains (Sweiger et al., 2006). This response has paralleled the decline in quail populations in the region. Documented impacts of elevated mercury levels in birds include lower reproductive success and abnormal behavior (William and Mary, 2014), neurological/physiological problems, and death.

We note here a study on Hg concentrations in bobwhite quail in Virginia (Turnquist and Evers, DC, 2012) that concluded, based on low Hg concentrations in wing feathers of field sampled quail, that Hg was not a toxic problem for Virginia quail. We suggest that quail wing feathers may not be an optimum comparative sampling tissue, particularly for this fast flushing bird. We consider that concentration of Hg in blood or internal organs would be a much more direct and better indicator of levels of physiologically active mercury.

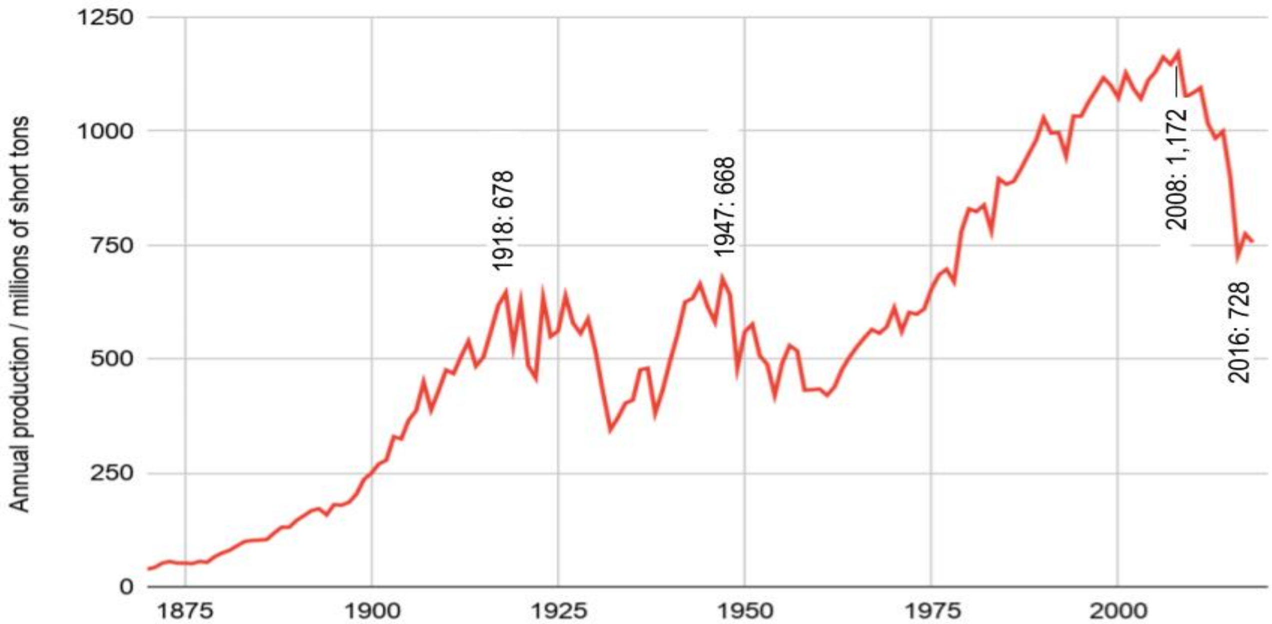
Table 3. Contributions of Coal Fired Power Plants to Selected Hazardous Air Pollutant Emissions

Hazardous Air Pollutant	Percentage of Point Source Emissions
Acid Gases (HCL and HF)	76%
Arsenic	60%
Beryllium	28%
Cadmium	30%
Chromium	20%
Cobalt	34%
Lead	15%
Manganese	46%
Mercury	46%

Atmospheric Lead Emissions

Lead is another by product of fossil fuel production and consumption (gasoline) as well as mining activities and it, like mercury, has been shown to damage developing neurological systems in humans**.** It can also accumulate in soils and sediments over time and cause damage to plants and animals. The long term record of lead emissions in the US (Figure 3) shows a strong increase in total lead emissions during the period leading up to and continuing with quail decline through year 2000. If one plots lead air quality over the last 30 years, however, one can see the positive effects of the switch to unleaded fuels in highway vehicles beginning around year 1995. Results of field sampling (Schmude et al., 2018) to determine lead uptake based on analysis of lead concentrations in feathers of field collected quail in Texas indicated that lead levels in 25% of sampled birds exceeded the toxic threshold (4 ppm dry weight), while 6% had Pb concentrations of 5 times the projected effects threshold.

Figure 3. Historical Emissions of Lead in the US 1876-2016.

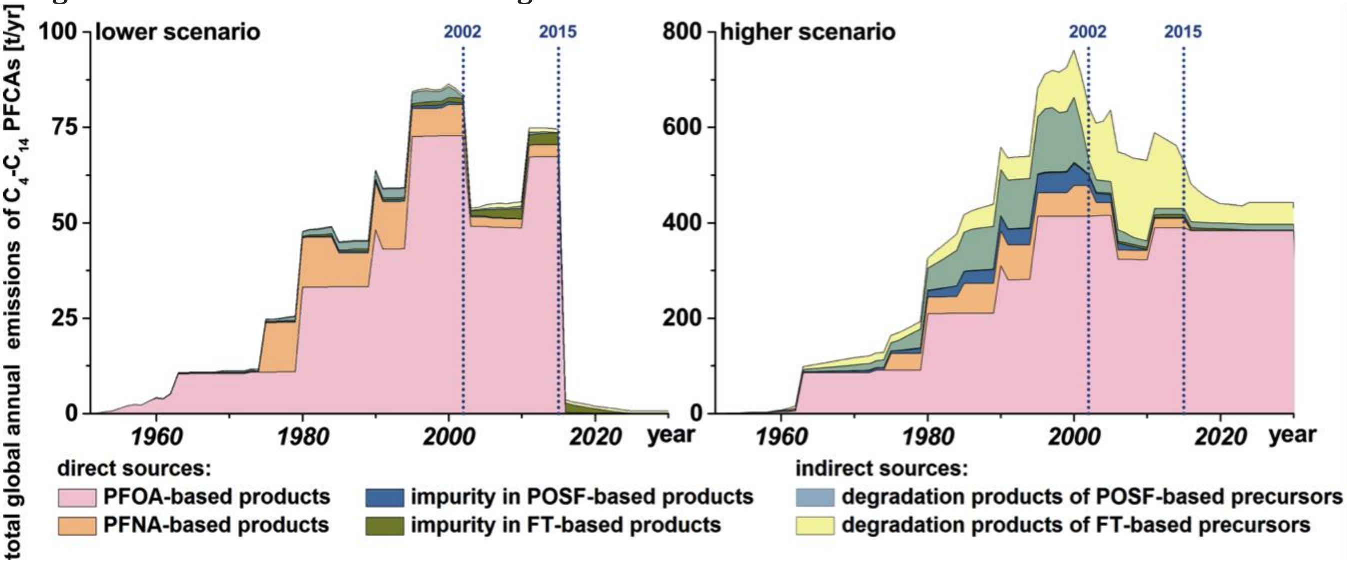


Release and toxicity of Polyfluorocarbons PFAs and PFSOs)

Since the invention of Teflon in 1938 the development of a diverse class of polyfluoronated synthetic organic chemicals has expanded to meet the diverse needs of industries. These industries include organic chemicals, plastics, and synthetic fibers, pulp and paper, textile mills etc. Along the way it was discovered that PFAS, can be toxic to humans, are not easily degraded over time and with decades of use have now shown up in surface water, drinking water, soil, plant and animal tissues and human blood serum across the globe (EPA, 2021). In a recent survey of regional drinking water supplies, public water systems in 33 states serving 6 million people had PFAS levels with at least one sample above the toxic threshold of 70ng/l. Recent studies to assess reproductive toxicity of mixtures of PFOA and PFOS demonstrated that these two compounds can act synergistically to cause adverse reproductive and growth effects in bobwhite quail at a level of 0.06 ppm (60 ng/l). a level of below the EPA joint exposure drinking water standard for adverse effects. The higher toxicity of the combined vs individual component exposures is an extremely important finding as we consider how to most realistically study real world mixtures of toxic substances.

Upper and lower level estimates of the total global emissions of PFOA and related products are shown in Figure 4. It is immediately apparent from this figure that rapid increases in global emissions of PFOA's were occurring in the same interval as that in which populations of quail were declining in the Eastern US.

Figure 4. Estimates of the historical global emissions of PFOA and Related Products 1960-2020.



Evaluating Concurrent Trends: Sensitivity and Causality

In Table 4 we have combined the comparative trend patterns for four potential causative pollutant stresses that may have influenced the timing, and level of response of the quail decline. These include emissions of acidity (S & N), and lead, mercury, and PFA'S vs the 5 state average pattern of quail population decline as well as the population decline in Virginia. The degree of correlation R between two variables allows one to calculate the percentage of total variability (R2) expressed by the dependent variable as a reflection of the variations in the independent variable over time. Table 4 indicates that 3 of the 4 independent variables (Hg, Pb, and PFOA+PFS) were strongly and negatively related to low values of quail survival (i.e., high levels of decline of quail populations). These variables appear to contribute over two thirds of the variability in 5-year interval quail decline time series expressed over the 40-year study interval. Correlations were similar in sign, but less significant for the comparisons that were restricted to Virginia alone. Emissions of S and N, which peaked well before the peak of the quail decline were inversely related in time to decline (i.e., lowest emissions associated with low survival) at either single state or 5-state scales.

Table 4. Correlation coefficients between 4 indicators of hazardous pollutants and rate of decline in bobwhite quail populations in 5 eastern US states.

Response Variable	Indicator of Pollution				
	Correlation	S+N	PB	HG	PFOA
5 State Average of D5*	R	0.83	-0.79	-0.88	-0.78
	R2	0.69	0.62	0.77	0.61
Virginia D5	R	0.91	-0.46	-0.83	-0.64
	R2	0.83	0.21	0.69	0.41

Note: *D5 is the decline in Quail population estimate on a 5 year interval basis compared to the five maximum annual counts within the 45 year sampling interval. Small numbers were associated with low populations

While proof of correlation is not the same as proof of causality, it can lead us to explore more effectively pathways that lead to proof of causality. The required response characteristics needed to establish proof of causality include sensitivity, consistency, and the existence of a plausible mechanisms linking causative factors to an observed response - in this case - quail decline. Our analysis suggests that three of the stress parameters examined meet the prescribed combination of relationships needed to establish proof of a causal linkage to quail decline. As both individual and combined toxicants we consider Hg, Pb, and PFOA as critically important candidates for further productive studies to strengthen the evidence and understand the nature of cause and effect linkages with quail decline.

Conclusions

We believe that sufficient data exist to conclude that atmospheric pollution has played a significant role in contributing to the widespread decline of bobwhite quail populations in the Eastern United states. Because field exposures to air pollutants involve concurrent exposure to multiple pollutants with the potential to affect multiple neurological and physiological processes, it will be important to study the potential interactive effects of pollutants combinations if we wish to better understand and perhaps remediate the regional reductions in quail populations. Field and lab based toxicological studies examining individual and combined effects of lead , mercury, and PFAs should be undertaken to better define the combined toxicity of these pollutants on quail and on their sources of food and water. In addition, the effects of acidic deposition on quail reproduction derived from calcium depletion and associated egg structural and physiological integrity should be explored.

We suggest, for many reasons, that bobwhite quail should be promoted as a model indicator species to study regional scale effects of air pollutants on terrestrial ecosystems in the Eastern United States. This recommendation is based on the documented existence of regional scale decline of quail across the region, widespread knowledge of and support for the species, specific habitat and feeding preferences that would make it susceptible, availability of a ready supply of birds and eggs for testing from commercial producers, and previous research findings with several pollutants. A well-coordinated program of extensive future experimentation could answer many important questions about ecosystem level responses to the current regional mix of air pollutants in the Eastern United States. Such experimentation should focus on the effects of both individual and combined pollutants and on interactions with other environmental stresses on decline of this species. The answers so provided would likely have important implications for the future ecological health of this important bird species as well as for some of the ecological systems that support many more species, including man,

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List of Figures and Tables

Figure 2. SO2 emissions from 3 eastern states from 1900 to 1980 show parallel trends in the timing of increases and reflect regional synchrony in industrial development over time.

Figure 3. Historical Emissions of Lead in the US 1876-2016.

Figure 4. Estimates of the historical global emissions of PFOA and Related Products 1960-2020.

Note: This research prospectus is being presented in hopes of stimulating comprehensive integrative research into the potential role of regional scale environmental pollution on eastern bobwhite quail health and survival. The proponents are W. Wilson, G. Brelsford, J. DiNardo, and S. McLaughlin, and they seek to promote, not receive, funding for this research. Wilson is an attorney with 15 years of experience in the Virginia General Assembly. A lifetime outdoorsman, Wilson promoted a large multidisciplinary, multiagency study to examine the effects of habitat restoration on quail populations in Virginia as one of his legislative initiatives. Bobwhite habitat improvement did not solve the problem. Brelsford retired from the paper industry after 32 years in process improvement, product development, and new product marketing roles. He co-chaired the Paper Recycling Technology task group for the American Forest & Paper Association from 1996 – 2000 to help increase paper recycling rates in the U.S. DiNardo is an industrial ecotoxicologist with 45 years of experience in assessing risks to humans from a variety of chemicals used in the health care industry. He holds several domestic and international patents for various chemical technologies. McLaughlin was a Senior Research Staff Member in the Environmental Sciences Division of Oak Ridge National Laboratory, where he worked for 30 years. He Participated in two national research teams that focused on effects of acidic deposition and ozone on terrestrial ecosystems in the United States and developed a wide variety of new analytical techniques for evaluating the effects of air pollutants on crops and forests. He also helped document both principal physiological mechanisms and regional variations in effects of acidic deposition on spruce-fir forests of the Eastern United States. He has over 196 publications in ecophysiology.