The value of an integrated statewide environmental report for Tennessee

Nathaniel L. Gibson[1*], Nicholas Mucci[2*], Daniel Sain[3*], Paul R. Armsworth[1]

1. Department of Ecology & Evolutionary Biology, University of Tennessee Knoxville

2. Genome Science and Technology, University of Tennessee Knoxville

3. Department of Biosystems Engineering and Soil Sciences, University of Tennessee Knoxville

* Authorship order determined by alphabetical order of last name.

Abstract

The environment is constantly changing, affecting the structure and function of ecosystems and impacting people's quality of life. Different agencies within the state of Tennessee monitor and report environmental data, but there is no single, easy-to-use, centralized report summarizing the range of observations made. We describe the need for an integrated environmental report for the state. State of the environment reporting has been done at the national level, but is less common for states. However, a clear precedent for state-level reporting in Tennessee has been set by an influential annual report on the state of the state's economy. We identify the steps necessary to synthesize a counterpart state of the Tennessee environment report. We also offer examples of the kind of environmental indicators it would be important for such a report to consider, presented in the form of an exemplar report. An annual state of the environment report will help Tennessee promote a sustainable and resilient future.

What is the state of environment reporting?

The condition and quality of our environment is critical for maintaining and improving the well-being of society. Society depends on goods and services from the environment like clean water, clean air, and agricultural outputs (1, 2). The condition of our environment is always changing, often due to how we use and interact with it (3). Therefore, it is imperative to carefully monitor environmental health and status. The process of examining trends in and the current state of the environment is known as state of the environment reporting (4, 5).

State of the environment reporting has been adopted both nationally and internationally in the past two to three decades. For example, the Heinz Center's State of the Nation's Ecosystems (2008) provided an overview of the quality of the United States natural resources, ecosystems and biotic communities to stakeholders including policymakers. That report developed indicators for various facets of the environment by following 5 principles: 1) focus on the condition and trends of a given indicator, 2) establish clear relevance to policy and regulatory issues, 3) employ an unbiased, balanced suite of indicators, 4) institute a high standard for quality of data coverage over space and time, and 5) synthesize findings and update periodically (4). However, reporting only national indicators might not provide adequate or appropriate information for individual states, such as Tennessee, due to differences in scale or measurement.

In this White Paper, we examine the value of integrating environmental data from monitoring agencies with a focus on Tennessee. Tennessee reports extensively on environmental data, but there is no annual centralized report summarizing key trends. Establishing this report will make informed environmental decision-making easier.

Why is the report needed?

Integrated state of the environment reporting provides greater accessibility of environmental monitoring data. Likely, all data presented in a state of the environment report would be already available from public sources, including federal or state agencies. However, different agencies are typically responsible for monitoring specific facets of the environment. This piecemeal approach results in a dispersion of relevant data across different reports and websites, which impedes developing a cohesive picture of what is happening to the environment as a whole. State of the environment reports from the United States and elsewhere focus on centralizing information from disparate monitoring agencies and facilitating access to that information for stakeholders (4-6). This type of integration requires establishing connections between major themes and indicators such that they provide a more holistic picture of environmental conditions. Through these practices, state of the environment reporting provides a summary of overall environmental status while also highlighting areas where data or monitoring might be lacking. Having a ready summary of environmental data in one place would save time and perhaps increase uptake of the data.

A state of the environment report provides value partly by analyzing observed trends in environmental indicators. A synthetic summary of long -term trends in environment indicators can help inform oversight and accountability of state agencies tasked with managing aspects of Tennessee's environment. A state of the environment report could also relate those trends to relevant regulatory standards at the state and federal level. In the absence of regulatory guidelines, other relevant benchmarks for comparison could perhaps be used. Disaggregating state-level data would also provide a means to compare how well specific areas (i.e. counties) are performing regarding environmental standards.

When considering how state of the environment reporting might be constructed and implemented, one can look to the Boyd Center's annual economic report for Tennessee as reference (7). The Boyd Center's economic report has been an impactful and effective tool for stakeholders (Box 1). This report touches on many economic themes and indicators that provide insight into how the Tennessee economy is performing. It also projects that performance into the future by examining trends. A report of the Tennessee environment which mirrors (to some degree) the structure of the Boyd Center report on the state of the state's economy can be – and should be – developed in the near-term.

"Decision-makers have data coming at them all of the time. One reason the annual report on the state of Tennessee's economy from the Boyd Center for Business and Economic Research became influential was because it collated that information in a single, easy-to-reference place. In effect, it created a common voice."

-Matt Murray, Director, Howard H. Baker Jr. Center for Public Policy and Associate Director, Boyd Center for Business & Economic Research

Box 1

What environmental reporting is already done?

While reporting on particular aspects of the environment is widespread, there is less organized and synthesized reporting. Good examples of comprehensive environmental reporting come from nationwide reports, like the Heinz Center report. Among federal agencies, the Environmental Protection Agency reports on a broad spectrum of environmental indicators (6) but does not produce a summary state of the environment report that synthesizes that data.

At the state level, environmental reporting can be fragmented. Tennessee, like most states, has a mix of environmental reporting. Environmental reporting comes not only from state agencies like the Tennessee Wildlife Resources Agency and the Tennessee Department of the Environment and Conservation, but also agencies like the Tennessee Valley Authority and the Environmental Protection Agency that work over larger scales. However, there does not appear to be a single, synthetic state of the environment report that integrates data from these different sources.

Some states produce more integrated state of the environment summaries that a state of the environment report for Tennessee could emulate. For example, New Jersey has made all of their reports on environmental data accessible through a single website (8). This website contains a library of reports on the state’s plants, wildlife, water, pollution, solid waste, open space, land use, climate, energy usage, and air quality. However, there still does not appear to be a regular summary of all this data, once again suggesting the value for such a document. There is a widespread, national need for synthesized state of the environment reporting and Tennessee could be a leader in this field.

The next steps needed to develop a state of the environment report.

> *"If you want stakeholders to use and value sustainability reporting, they must be involved in the co-creation of the reporting process from the beginning. This involves a structured process of engagement that starts by bringing together multiple perspectives to carefully articulate shared values and a vision for success. Followed by the selection of recognizable, practical, and achievable indicators that integrate bottom-up and top-down measures. This process is not easy nor linear, but it is essential to capture the lived experience and wisdom of stakeholders and to make sure they are invested and take ownership of the sustainability and resilience of their community."*
>
> - Thomas Grey, Research Fellow, TrinityHaus at Trinity College Dublin and Co-author of "Indicator and Stakeholder engagement: a Dublin case study"
>
> Box 2

Experiences developing state of the environment reporting elsewhere (e.g., Siddall et al 2013; Box 2) suggest a set of steps to be taken (Figure 1). First, workshops with relevant stakeholders need to be convened. This is to ensure major themes for environmental indicators, and the extent and grain of those indicators, are as relevant as possible to potential users of the report (Figure 2). There is a plethora of environmental data available and analysis of these data needs to be prioritized based on stakeholders needs and quality of the datasets.

After initial development, recurrent, perhaps annual, meetings should be scheduled to discuss the next iteration of the report and any refinements or additions necessary for it to remain relevant. This will guarantee clarity regarding specific environmental target goals and measurement practices, as well as evaluate new or alternate data sources. State of the environment reporting is most useful if it is synthesized and updated periodically, as it allows stakeholders to appraise whether actions they have taken have changed aggregate trends in the environment.

Figure 1: Process of drafting an integrated Tennessee state of environment report, from initial development to annual evaluation and republishing.

Both initial development of a state of the environment report as well as periodic updating of that report will require funding. Relative to primary research, the funding amounts involved are likely much more modest, because no further primary data collection on environmental indicators is involved. Instead, the work is in facilitating stakeholder workshops, collecting and analyzing existing data, and writing. Long-term, if production of an aggregated environmental report is useful to stakeholders, we anticipate its funding would be provided by those users. However, initial development of any such report – something needed to evidence its usefulness – will likely require securing grants or other funding.

In the following sections, we seek to exemplify some of the steps (Figure 1) involved in the state of the environment reporting for Tennessee. The structure and format for any such report should be determined by stakeholders who would use the report. Here, for illustrative purposes, we focused on four major themes: the state of air, land, biodiversity, and water across Tennessee (Figure 2).

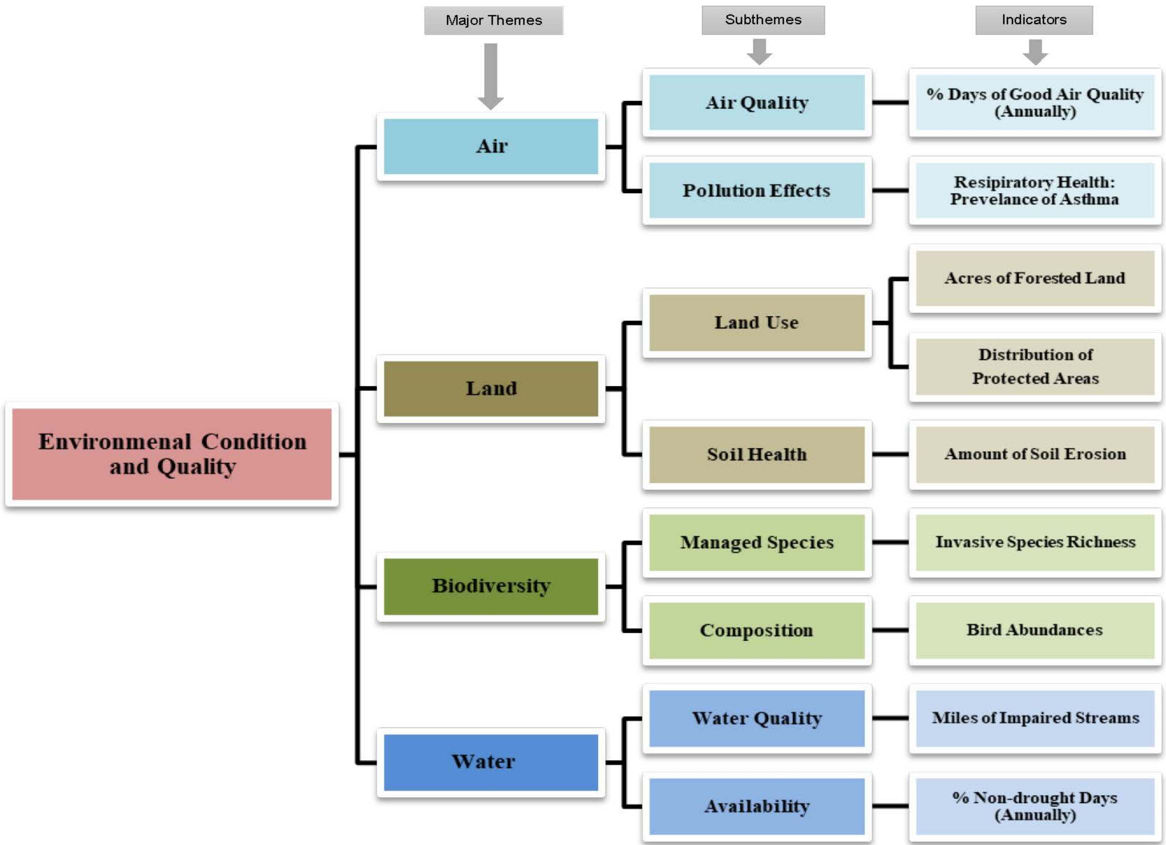

Figure 2: Flow chart depicting indicators we identified, relating to the major environmental themes of air, land, biodiversity, and water, that convey the condition and quality of the environment.

For each major theme, we identified indicators to quantify trends in the state of the environment since the year 2000 (Figure 2). Again, indicator choice for a full state of the environment report would be determined by stakeholders and users of the information being provided (Box 2). We provide a few examples of possible indicators for each theme, focusing on ones for which data are relatively straightforward to collect and evaluate. Our analyses focused mainly on statewide trends. Finer scale reporting is possible (i.e. at the county level) for some indicators but not all due to data collection methods. A complete state of the environment report would include more indicators reported with finer granularity and benchmarking against regulatory standards.

Modeling future projections for indicators over the next 5-10 years could be another valuable addition. While gaining an understanding of historical and current conditions provides necessary context, short-term forecasting for indicators can provide for better informed public policy and decision making. Essentially, it would allow policy and decision making to be preemptive or preparatory. Forecasts could be carried out through several means, including statistical modelling or surveying experts. We believe a combination of the two will provide for the most complete approach, wherein a panel of experts can be surveyed annually to consider results and implications of modelled outcomes for indicators.

Exemplar Report: Executive Summary

Having described the utility of integrated environmental reporting for Tennessee, in the following sections we exemplify what such a report would entail by drafting an abridged version. In this exemplar report, we focused on examining environmental trends since 2000. In any full report, these trends should be benchmarked with governmental regulations on what is acceptable environmental conditions, a step we have not yet made.

In terms of trends, we found that indicators for land and air are generally increasing or stable across the state, while indicators for biodiversity and water are often associated with negative environmental impacts (Table 1). Though we do not provide short-term forecasting, we anticipate that a full state of the environment report may well want to do so and to provide further disaggregation of statewide data to counties or other jurisdictions than we have included here.

Theme	Subtheme	Indicator	Trend	Impact
Air	Air Quality	% Good AQI Days	Increasing	Positive
	Pollution Effects	Prevalence of Asthma	N/A	Variable
Land	Land Use	Hectares of Forested Land	Stable	Positive
		Distribution of Protected Areas	N/A	Variable
	Soil Health	Amount of Soil Erosion	Stable	Positive
Biodiversity	Managed Species	Invasive Species Richness	Increasing	Negative
	Composition	Abundance of Birds	Decreasing	Negative
Water	Water Quality	Miles of Impaired Streams	Increasing	Negative
	Availability	% Non-Drought Days	None	Variable

Table 1: Results from indicators analyzed in exemplar report. Trends represent changes over time. N/A means that the indicator was visualized as a spatial distribution, not over time, thus no trend could be established. Impact indicates whether the particular trend is beneficial or detrimental for Tennesseans.

Trends in air quality in Tennessee

Air quality is a pertinent factor to consider when addressing the state of the environment, as it can have direct impacts on public health (10). The Clean Air Act passed in 1970 and has helped to improve air quality nationwide with direct positive health effects for people (11). Still, air pollution concerns will remain particularly as urbanization increases, including in Tennessee (12).

Two sub themes related to air quality are addressed in this section, which also identifies possible areas for improvement. The first subtheme considers temporal trends in air pollution across the state by monitoring days of good air quality using the air quality index (AQI). The second subtheme addresses the direct effects of air pollution by investigating cases of respiratory illness and how our state compares nationally.

The AQI is calculated by taking into consideration levels of five major air pollutants regulated by the Clean Air Act: ground-level ozone, particle pollution, carbon monoxide, sulfur dioxide, and nitrogen dioxide. To develop a summary indicator, we gathered AQI data from the EPA (see Methods) and converted these data into ratios of good air quality per year. Overall, air quality in Tennessee has been improving over the past two decades (Figure 3). Tennessee had roughly 55% of good air quality days in 2000 compared to 85% good air quality days in 2019. Tennessee is now comparable to states like Oregon which have 83% good air quality days (13).

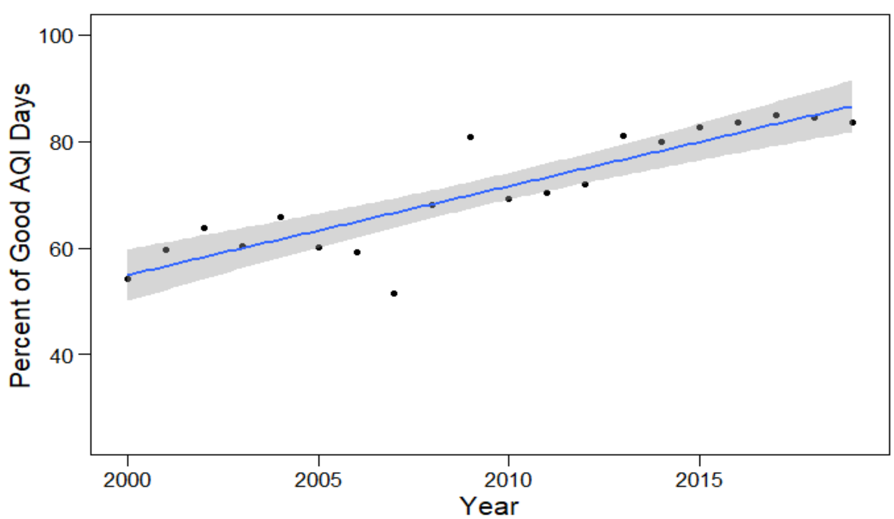

Figure 3: Trends in air quality from 2000 to 2019. Percentages were calculated from a ratio of good air quality days to days of worse air quality. Line represents regression line while

shaded area represents the confidence interval ($p<0.0001$; $r^2 = 0.78$). Data gathered from the EPA's Air Quality Index.

Despite this overall positive trend, there may still be room for improvement in specific areas. One metric of how AQI can be measured is through particle pollution, such as sulfates emitted from coal-fired power plants. Combustion associated with these plants can cause an increase in the amount of sulfur dioxide present in the air (14). The American Lung Association ranks major metropolitan areas in terms of their annual particle pollution. The Knoxville-Morristown-Sevierville area was ranked 25th out of 203 areas nationally in terms of particulate pollution (15). Other aspects of air pollution that contribute to the AQI (i.e. ozone and carbon monoxide) could be individually reported in a state of the environment report to see how counties in Tennessee compare to each other and national trends.

Respiratory illness can be exaggerated and worsened due to air quality in an area, resulting in more frequent and severe symptoms. Moderate or bad air quality days will cause flare ups in symptoms of sensitive individuals. Annually, the Asthma and Allergy Foundation of America produces a report which aims to reduce the burden of asthma on communities across the nation. They report cities with the highest estimated asthma prevalence. Strikingly, of the ten major metropolitan areas with highest estimated asthma prevalence, four are cities in Tennessee: Nashville, Chattanooga, Knoxville, and Memphis (Figure 4; 16). Two of these cities, Chattanooga and Memphis, reside in counties which had a far lower proportion of good AQI days than the state average for the year – 65.2% and 66.5%, respectively, compared to an 85% statewide average. Mapping data across the state also reveals widespread AQI monitoring gaps; less than 33% of Tennessee counties had data available in 2019. This highlights the need to collect data in unreported counties to gain a better understanding of air quality across a broader range of the state.

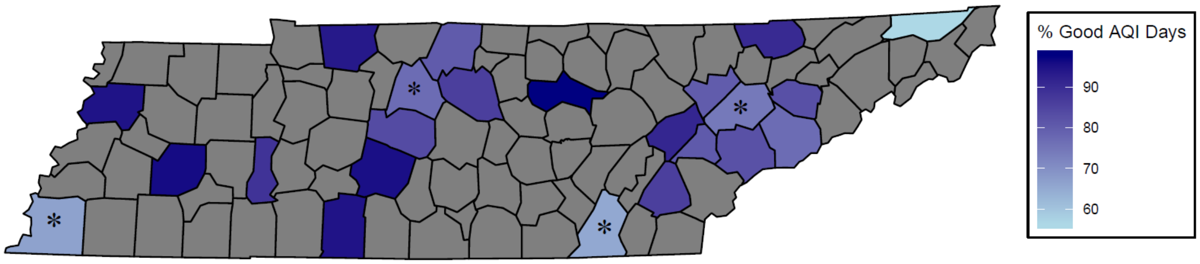

Figure 4: Map showing air quality for most recent year (2019). Light blue-navy blue gradient represent % Good Air Quality Index (AQI) Days for 2019. Gray counties did not have data available from the EPA; black asterisks represent counties with cities listed on Asthma and Allergy Foundation Top Ten Metropolitan Areas with Highest Estimated Asthma Prevalence.

Other metrics that might be candidates for monitoring and reporting would compare incidence of other respiratory illnesses, like Chronic Obstructive Pulmonary Disease (COPD) or lung cancer, to nationwide averages. A detailed analysis of where cases of respiratory illness occur across the state would be particularly useful.

These indicators and trends illustrate how air quality could be used as one aspect to report on in an integrated state of the environment report. In doing so, the metrics listed above should be expanded based on input from stakeholders. There are serious health risks related to air quality, and we believe a comprehensive state of the environment report would closely examine indicators describing air quality.

Trends in land use and quality in Tennessee

There are a broad range of terrestrial ecosystems across Tennessee, which encompasses roughly 10.5 million hectares of land (17). Tennessee uses this land for growing crops, timber, recreation and conservation areas like state and national parks, and more. However, Tennessee only has a limited amount of land and once land is changed or disturbed, it can rarely be returned to its natural state (18). In addition to how land is used, the condition of Tennessee's lands is also important. Take, for example, the issue of loss of topsoil through erosion – it will take almost a hundred of years for a new inch of soil to form (19). Several economic sectors (agriculture, recreation etc.) in the state of Tennessee depend on reliable access to quality land resources. Our farms, cities, roads, and much of our lives depend on the land being able to accommodate our needs. With that in mind, the quality and usage of land should be carefully monitored.

To exemplify how a state of the environment report for Tennessee might consider the health of terrestrial ecosystems, we focused on two sub themes: land use and soil health. Land uses convey how land has been developed and its current utility, including everything from agricultural and industrial areas to residential properties (20). Soil health is critical to maintaining productivity of the land and sustaining plant and animal populations (21).

To illustrate the sort of indicators that state of the environment reporting could consider, we quantified the area of forested land (hectares) over time and examined distributions of protected areas (hectares) as two pertinent indicators for land use. With respect to forest extent, Tennessee historically has averaged about 53% of the state being forested. Roughly 83% of that forest is owned by private individuals or companies, and the rest is under federal or state management (17). Overall, the amount of forested land has remained relatively stable over the past 20 years (Figure 5). Tennessee forests are important for several reasons. Tennessee is a national leader in timber production (22). Maintaining the current amount of forested land, possibly through sustainable forestry practices or conservation-minded protection, would aid in keeping timber production steady now and in the coming years. Additionally, forests are important sinks for carbon sequestration, especially as atmospheric carbon levels are rising across the globe (23).

With these considerations in mind, our current maintenance of forested land in the state of Tennessee is positive for the state.

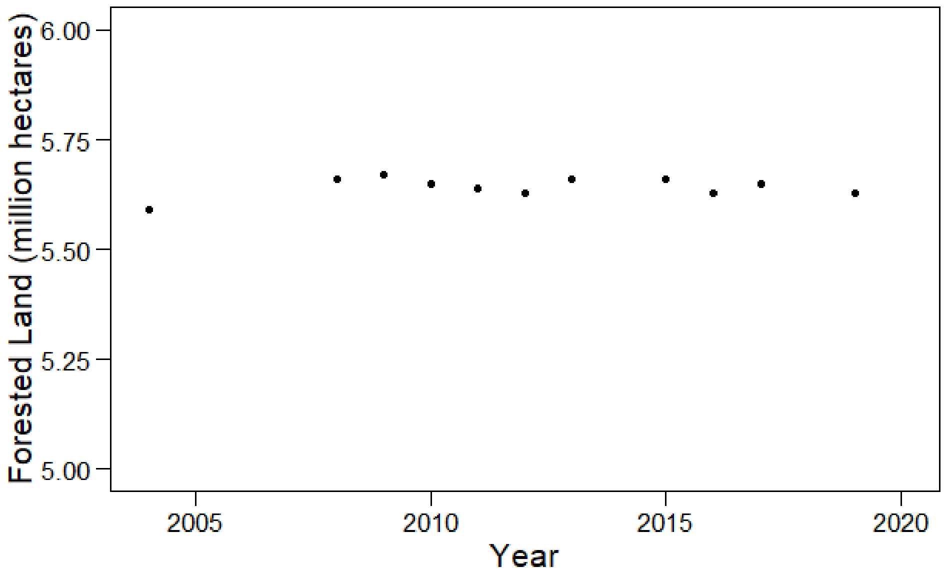

Figure 5: Change in amount of forested land (million hectares) over time in Tennessee. Data gathered from the USDA Forestry Service.

The second indicator for land use examines the distribution of protected land within Tennessee. Of Tennessee's 10.5 million hectares of land, roughly 1 million of those hectares are protected land that is state or federally owned (24). The greatest share of these protected lands are found in eastern Tennessee (Figure 6). Protected areas have a range of goals including preserving the natural world and providing recreation opportunities. Research has demonstrated that access to green space and natural areas can play an important role in mental and physical health (25). Protected areas are also important economically due to tourism revenues from state and national park visitors, such as Great Smoky Mountains National Park providing over $800 million in economic benefits to nearby communities (26). Where protected areas are located, then, could have tangible effects on public health and economic opportunities for Tennessee residents.

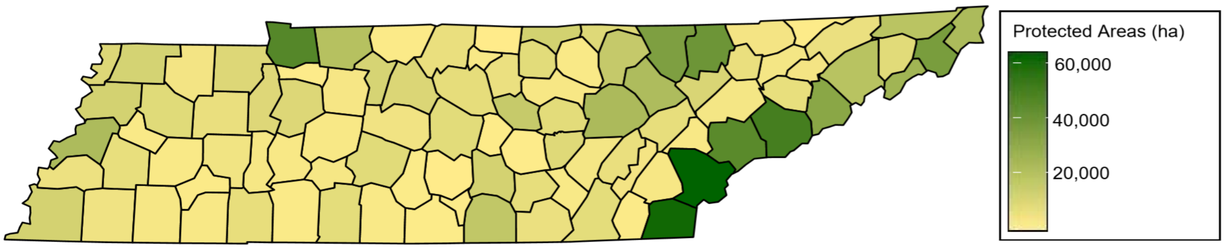

Figure 6: Hectares of protected land across Tennessee by county. Green-yellow gradient represents the number of hectares in the given county. Data gathered from USGS Protected Area Database of the United States (PAD-US).

We also considered how the condition of terrestrial ecosystems might be examined by focusing on levels of soil erosion over time as an indicator for soil health. While soils may seem like a static system, they are in fact highly dynamic (27). One of the most dominant forms of change that soils experience is erosion, or the loss of surface soil. In the last twenty years, there has not been a significant change in levels of soil erosion (Figure 7). Nevertheless, there have been longer-term losses due to soil erosion. In the 1980s, Tennessee was experiencing double the rate of soil loss as it is today (19).

Soil erosion is an important indicator when discussing ecosystem health, as it typically is associated with topsoil. Topsoil is the most productive part of a soil profile for plant growth and production (28), making it vitally important for agriculture. Excessive soil erosion can drastically reduce the productivity of Tennessee farms, and must therefore be monitored, planned for, and controlled. Furthermore, sediment pollution related to erosion is a leading cause of degradation for streams in Tennessee (29). Though historical measures of erosive soil loss are worrisome, recent stabilizations of total soil erosion could point to a possible turning point in the soil health of Tennessee lands.

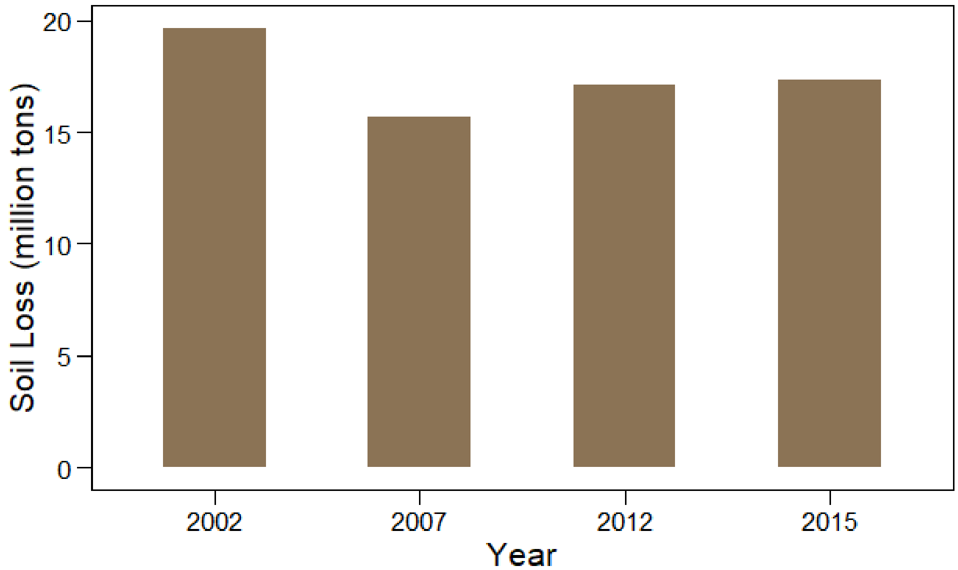

Figure 7: Trends in soil loss in Tennessee. Data gathered from NRCS National Resource Inventory.

Together these three indicators exemplify considerations that a state of the environment report for Tennessee could address regarding the condition of land resources and how healthy that land is. But again, our goal in this section is to exemplify and a full state of the environment report likely would integrate many additional indicators of how Tennessee's lands are changing.

Trends in biodiversity in Tennessee

Biodiversity is integral to a healthy environment, as it can promote function, stability, and resiliency within ecosystems (30-32). Biodiversity helps support many benefits from ecosystems that improve human well-being – from water filtration to cultural importance of species (33). Despite efforts to conserve biodiversity nationwide and globally, biodiversity losses continue to rise (3). Given that Tennessee is known in part for its diverse freshwater and forest ecosystems (34), biodiversity declines underscore the need for additional and increased focus on this topic.

The term biodiversity can have a broad interpretation, though here it is best understood as describing the number of species and abundance of those species across the state. To exemplify how biodiversity might feature in a Tennessee state of the environment report, we identified two subthemes which convey some of the critical aspects of biodiversity. First, we used a subtheme focused around managed species, including invasive species that can have major environmental and economic ramifications as they proliferate (35). Second, we focused on the composition of ecological communities, including factors such as species richness and population sizes to assess how biotic communities have changed over time.

From these subthemes, we developed several indicators that serve to quantify the state of biodiversity throughout Tennessee. We first used the number of invasive species recorded per year as an indicator for managed species. We utilized a database generated and maintained by the University of Georgia's Center for Invasive Species and Environmental Health (see Methods). The number of invasive species recorded each year has significantly increased since 2000 (Figure 8). Invasive species can pose several problems, including by decreasing native species richness, homogenizing biotic communities and perhaps most notably, further endangering at-risk species (34, 36). Indeed, the number of species protected by Tennessee Wildlife Resources Agency under the state wildlife action plan (SWAP) has been expanding over the same time period (Figure 9), possibly due in part to invasive species impacts. Furthermore, the spread of invasive species can pose problems for public health as they are known to increase infectious disease prevalences (37). Invasive species also have high economic costs, both in terms of management costs and lost production (38). Monitoring of invasive species could possibly be expanded to determine invasive hotspot areas, where intervention is more readily needed.

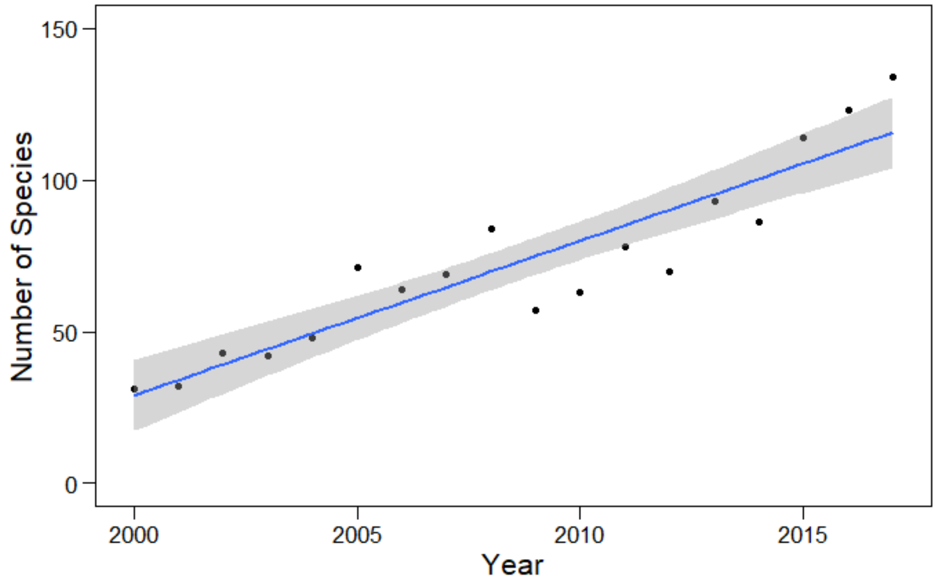

Figure 8: Number of invasive species (richness) observed per year, omitting 2018 and 2019; line represents the regression line with shaded area representing confidence intervals ($p<0.0001$, $r^2 = 0.84$). Data gathered from UGA Center for Invasive Species and Environmental Health.

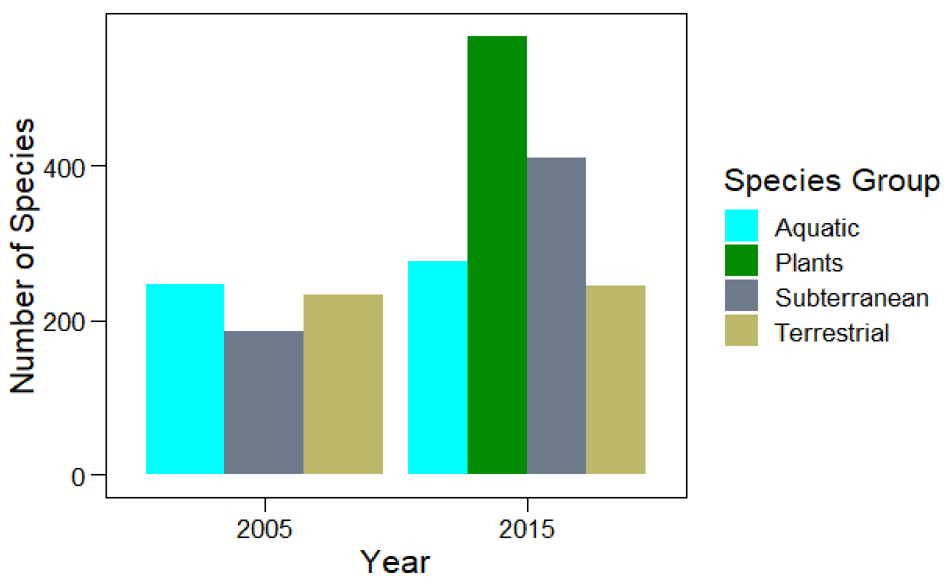

Figure 9: Number of species of greatest conservation per species group from 2005 SWAP and 2015 revision SWAP. Data gathered from Tennessee Wildlife Resources Agency.

The indicator we used for composition was the abundances (i.e. population size) of breeding and non-breeding birds in Tennessee since

2000, using data provided by the United States Geological Service (see Methods). While this indicator could be used for other taxa (insects, fish etc), several factors contribute to the utility of using birds as a biodiversity indicator including: 1) birds have been extensively surveyed, with data available going back decades, 2) birds are widely distributed and have a high dispersal, which works to provide a greater perspective than other communities, and 3) birds are highly sensitive to both anthropogenic and natural environmental change, thus providing insights into environmental health (7, 39).

Population size was examined instead of species richness in part to elucidate patterns which may have been hidden at the species level. From 2000 to 2018, the number of species observed fluctuated between approximately 125 and 140 species per year. However, such fluctuations can be readily explained by the presence or absence of rare species (i.e. only a handful or single individual observed) during a given year. In terms of abundance, the bird population of Tennessee has experienced a significant decline, dropping from 29,199 in 2000 to 17,234 in 2018 (Figure 10). This 41% decrease mirrors what studies have shown for other organisms such as insects (40) and globally across all species (41). With birds providing ecosystem services like seed dispersal, pollination and recreation (hunting or bird watching) (42), declines in bird populations could be indicative of decreases in environmental health and quality.

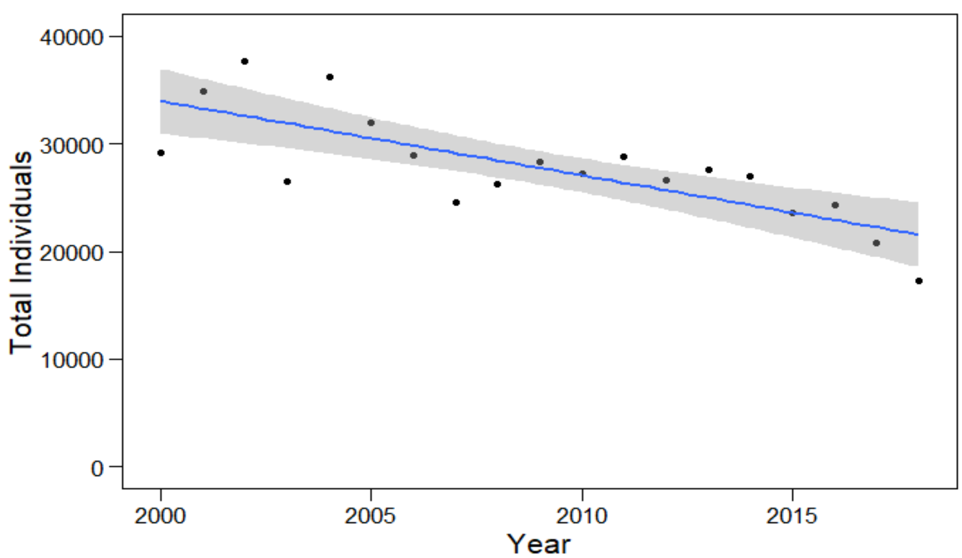

Figure 10: Population size across breeding and non-breeding birds in Tennessee per year, line represents the regression line with shaded area representing the confidence intervals ($p<0.0001$, $r^2 = 0.60$). Data gathered from the USGS Breeding Bird Survey.

Altogether, it would appear that biodiversity in Tennessee is in a precarious position based on these annual trends. Spreading of invasive species across the state could amplify the risks to biodiversity, while bird populations across the state have been steadily declining. If biodiversity continues to decline, there could be associated declines in human well-being (43). A complete state of the environment report could expand biodiversity indicators by considering populations of other species or habitat availability over time and future projections.

Trends in water in Tennessee

Water is a critical resource for all forms of life. Human communities depend on ready freshwater availability and utilize water in many ways, while many plants and animals live in and depend on aquatic habitats. There can be periods of time where access to abundant clean water is impaired, with devastating public health, economic, and environmental effects. These effects should be particularly important to Tennessee, as our state boasts exceptionally diverse freshwater ecosystems in the United States (44). Water is very likely a major, organizing theme in any full state of the environment report.

A state of the environment report for Tennessee is likely to include two main subthemes related to water. The first considers the quality of the water that is available in Tennessee. To exemplify what this might look like, we determined how miles of impaired streams in the state have changed over time. The second subtheme concerns water availability in Tennessee. Here, we examined the amount and severity of drought days in the state per year since 2000.

As an example of a candidate indicator for water quality in Tennessee, we investigated how the miles of impaired streams have changed over time using data available in TDEC 305b reports (see Methods). These reports give a mileage count for the total stream length impaired in Tennessee, as well as the total length of assessed streams and unimpaired streams. In Tennessee, there are approximately 60,000 miles of streams and rivers (29). Our analysis showed that the total miles of impaired streams has steadily increased while that of unimpaired streams decreased; the overall amount of streams assessed remained relatively constant (Figure 11). Water quality can have a range of impacts on humans and wildlife. Bodies of water can have varying levels of impairment, which bring differing restrictions on safe uses ranging from restrictions on fishing to determining whether the water is unsafe to drink or come into contact with (29). Impairment of streams limits the recreational value of Tennessee’s waters and the availability and cost to provide basic needs like drinking water to Tennessee citizens. Stream impairment also impacts economically and environmentally valuable species living within Tennessee’s waters (29, 34).

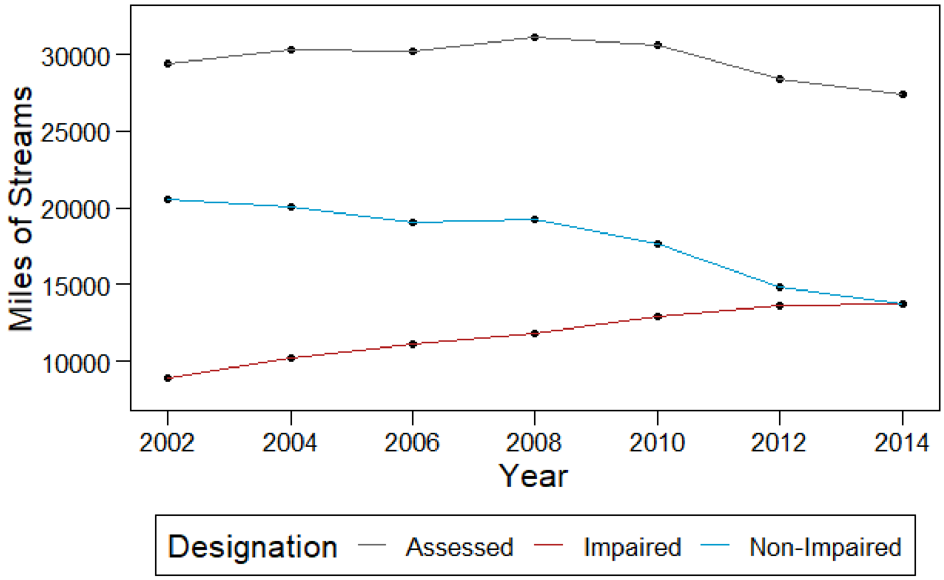

Figure 11: Impaired miles of stream trends. Line color represents the designation of stream for assessed total streams (gray), impaired (red), and non-impaired (blue). Data gathered from the Tennessee Department of Environment and Conservation.

As an example of an indicator of water availability, we examined how drought conditions have changed over time in Tennessee. There is no overall trend in drought conditions. Instead, occasional major droughts occur that the state needs to prepare for (Figure 12). Severe droughts can affect streams significantly, resulting in a dramatic loss of water availability (Figure 13). As Tennessee contains particularly diverse aquatic ecosystems (44), droughts can have an outsized impact on freshwater species (45). Droughts can also severely impact human use of water. Tennessee is a large producer of hydroelectric power, and when drought conditions are severe or persist long enough it can limit hydroelectric energy production (46). Droughts also limit both the domestic and commercial use of water by humans. During severe droughts, home consumption of water must be decreased, and farmers are not able to adequately irrigate crops.

It is important that the state recognizes the impact of droughts environmentally and economically because the intensity and occurrence of droughts could increase with the increase in atmospheric carbon and the impacts that has on climate (47, 48). A longer time series than we are showing would be needed to evaluate such a hypothesis for Tennessee. Potential climate impacts on instream flow rates also highlight the value of including projection work that takes recent conditions and forecasts what may be coming in state of the environment reporting.

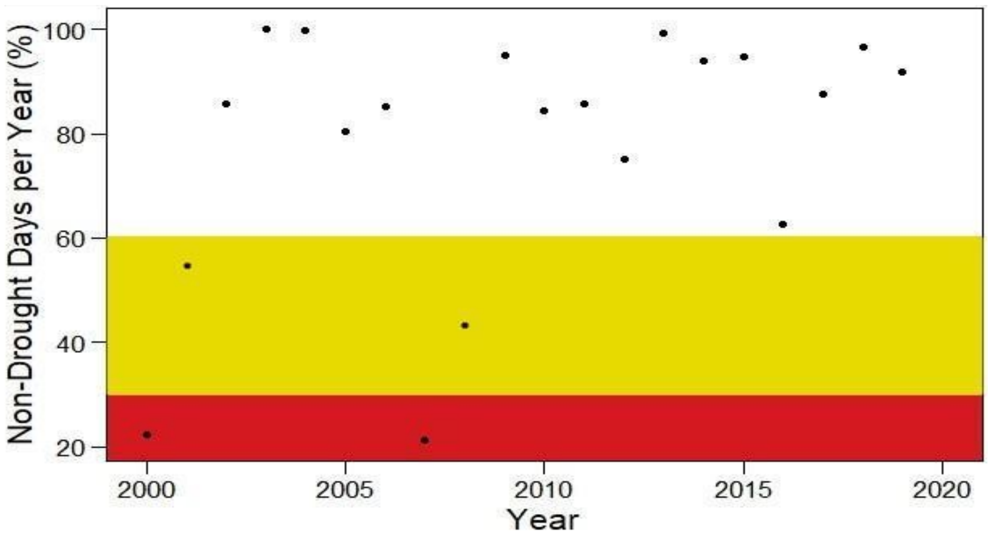

Figure 12: Drought conditions for Tennessee, from 2000 to 2019. The red area represents years of very severe droughts (roughly 30% of days in a year without drought); the yellow area represent years of moderate droughts (approximately 30%-60% of days in a year without drought). Data gathered from the National Integrated Drought Information System.

Figure 13: Pictures show the same stretch of creek at two different timestamps. The left hand photo was taken during drought conditions in June 2017. The right hand picture was taken at normal flow levels (photo credit: Daniel Sain).

Access to abundant clean water is a resource we all take for granted. Tennessee needs to monitor trends surrounding state waters to ensure the health and well-being of all residents. A full state of the environment report displaying long term trends and how these affect water quality and quantity will help policymakers determine water use guidelines. Water is a critical asset to our state that needs to be protected.

Methods

Air quality data were downloaded from the Environmental Protection Agency (EPA) at: https://aqs.epa.gov/aqsweb/airdata/download_files.html. Annual AQI data was extracted from 2000 to 2019. Data are represented as a percentage of Good AQI days compared to days of worse AQI. Respiratory illness data were compiled by the Asthma Capitals 2019 report and the American Lung Association.

Data on forestry were from the "Tennessee State and Private Forestry Fact Sheet." This is an annual report and data from multiple reports were combined. Protected land data were downloaded from the US Geological Surveys Protected Area Database of the United States (https://www.usgs.gov/core-science-systems/science-analytics-and-synthesis/gap/science/protected-areas). We included all protected areas overlapping Tennessee counties classified as being of GAP 1-3 type in the database. Data on soil loss were taken from the National Resource Inventory that is managed by the National Resource Conservation Service (https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/nri/).

Data for greatest conservation need species were compiled from the 2005 and 2015 SWAP documents, available at: http://www.tnswap.com/. Please see SWAP 2015 for elaboration on what constitutes a greatest conservation need species. Data for invasive species were provided by the University of Georgia Center for Invasive Species and Environmental Health, which receives records from federal sources (https://www.eddmaps.org/tools/statereport.cfm?id=us_tn). Reporting changes meant we could not yet include data from 2018 and 2019. Data on bird populations were from the USGS Breeding Bird Survey database, which provides data on annual counts of birds dating back to the 1960's, available at : https://www.usgs.gov/centers/pwrc/science/north-american-breeding-bird-survey?qt-science_center_objects=4#qt-science_center_objects

Drought data were from the National Integrated Drought Information System (NIDIS) at: https://www.drought.gov/drought/states/tennessee. Data were extracted from 2000 to 2019, and calculated the percentage comparing days of no drought to days of any drought. Percent non-drought days per year was calculated using a ratio of non-drought days to days of any severity drought. For this report, we did not differentiate based on drought severity, although the data would allow for this. Data on water quality were taken from the TDEC 305(b) reports that lists, in part, impaired waters in the state available at: https://www.tn.gov/environment/program-areas/wr-water-resources/water-quality/water-quality-reports---publications.html. Reports were only available from 2002 to 2014. Water was considered impaired if it was listed as category 4 or 5, and non-impaired if it was in category 1 or 2. Please refer to TDEC reports (e.g. 29) for definitions of impairment categories.

Trends data were analyzed using general linear models to determine how trends changed over time. Fitted trend-lines and confidence intervals were included on graphs for statistically significant trends. Trends were considered significant if $p < 0.05$. If no trend line is shown, then relevant slope coefficients were not significantly different to zero. All statistical analyses were carried out in R (v3.5.3).

References

1. Costanza R., Daly H.E. (1992). Natural capital and sustainable development. Conservation biology, 6(1), 37-46. https://doi.org/10.1046/j.1523-1739.1992.610037.x
2. Carpenter S.R., Mooney H.A., Agard J., Capistrano D., DeFries R.S., Díaz S., ... Perrings C. (2009). Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. Proceedings of the National Academy of Sciences, 106(5), 1305-1312. https://doi.org/10.1073/pnas.0808772106
3. Rockström J., Steffen W., Noone K., Persson Å., Chapin F.S., Lambin E.F., ... Nykvist B. (2009). A safe operating space for humanity. Nature, 461(7263), 472-475. https://doi.org/10.1038/461472a
4. H John Heinz III Center for Science, Economics and the Environment. (2008). The State of the Nation's Ecosystems 2008. Retrieved from: http://cfinsights.issuelab.org/resources/11234/11234.pdf
5. Jackson W.J., Argent R.M., Bax N.J., Bui E., Clark G.F., Coleman S., ... Wienecke B. (2016). Australia state of the environment 2016. https://doi.org/10.4226/94/58b65510c633b
6. United States Environmental Protection Agency. (2018). Report on the Environment (ROE). Retrieved from https://cfpub.epa.gov/roe/indicator.cfm?i=84#4
7. Murray M. (2019). An economic report to the governor of the State of Tennessee. Boyd Center for Business and Economic Research. Retrieved from: https://haslam.utk.edu/sites/default/files/erg2020.pdf
8. NJ Dept of Environmental Protection. (2020). Retrieved from: https://www.state.nj.us/dep/index.html
9. Siddall E., Grey T., Dyer M. (2013). Indicators and stakeholder engagement: A Dublin case study, Proceedings of the Institution of Civil Engineers: Engineering Sustainability, 166, (2), p85-97. https:doi.org/10.1680/ensu.12.00004
10. Craig L., Brook J.R, Chiotti Q., Croes B., Gower S., Hedley A., Krewski D., Krupnick A., Krzyzanowski M., Moran M.D., Pennell W., Samet J.M., Schneider J., Shortreed J., Williams M. (2008). Air pollution and public health: a guidance document for risk managers. J Toxicol Environ Health;71(9-10):588-698. https://doi.org/10.1080/15287390801997732.
11. Ross K., Chmiel J.F., Ferkol T. (2012). The impact of the Clean Air Act. The Journal of pediatrics, 161(5), 781–786. https://doi.org/10.1016/j.jpeds.2012.06.064
12. Power A.L., Tennant R.K., Jones R.T., Tang Y., Du J., Worsley A., Love J. (2018). Monitoring Impacts of Urbanisation and Industrialisation on Air Quality in the Anthropocene Using Urban Pond Sediments. Front. Earth Sci. https://doi.org/10.3389/feart.2018.00131
13. Oregon Health Authority. (2019). Air Quality: Air Quality Index. 3p. Retrieved from: https://www.oregon.gov/oha/PH/ABOUT/Documents/indicators/airquality.pdf
14. Dittenhoefer A., De Pena R.G. (1980). Sulfate aerosol production in coal-fired power plant plumes, Atmospheric Environment. Volume 16, Issue 6, 1982. 1323-1331, https://doi.org/10.1029/JC085iC08p04499

15. American Lung Association. (2019). Most Polluted Cities. Retrieved from: https://www.lung.org/our-initiatives/healthy-air/sota/city-rankings/most-polluted-cities.html
16. Asthma and Allergy Foundation of America. (2019). The Most Challenging Places to Live With ASTHMA. 6-11. Retrieved from: https://www.aafa.org/media/2426/aafa-2019-asthma-capitals-report.pdf
17. USDA Forest Service. (2020). Tennessee State and Private Forestry Fact Sheet. Retrieved from https://www.stateforesters.org/wp-content/uploads/2018/07/Tennessee-2018.pdf
18. Jackson S.T., Hobbs R.J. (2009). Ecological Restoration in the Light of Ecological History. Science. 567-569. https://doi.org/10.1126/science.1172977
19. National Resource Inventory (NRI), National Resources Conservation Service (NRCS). (2015). Tennessee Soil Erosion. Retrieved from: https://www.nrcs.usda.gov/Internet/NRCS_RCA/reports/nri_eros_tn.html
20. Anderson J.R. (1976). A land use and land cover classification system for use with remote sensor data (Vol. 964). US Government Printing Office.
21. Doran J.W., Zeiss M.R. (2000). Soil health and sustainability: managing the biotic component of soil quality. Applied Soil Ecology, Volume 15, Issue 1, 3-11. https://doi.org/10.1016/S0929-1393(00)00067-6
22. English B., Menard J., Jensen K. (2004). Tennessee's Forest and Forest Products Industry and Associated Economic Impacts for 2000. UT Institute of Agriculture. Retrieved from: https://ag.tennessee.edu/arec/Documents/AIMAGPubs/EconomicContributionandImpactStudies/AgricultureandForestry/TNForestEconImp2000wAppBandC.pdf
23. Cannell M.G.R. (1996). The Commonwealth Forestry Review. Vol. 75, No. 1, SPECIAL ISSUE: FORESTS AND CLIMATE, 92-99. Retrieved from: https://www.jstor.org/journal/commforerevi
24. Protected Area Database of the United States (PAD-US). (2018). US Geological Survey 2018. US Geological Survey, Gap Analysis Program. Retrieved from: https://www.usgs.gov/core-science-systems/science-analytics-and-synthesis/gap/science/pad-us-data-download?qt-science_center_objects=0#qt-science_center_objects
25. Groenewegen, P. P., Van den Berg, A. E., De Vries, S., Verheij, R. A. (2006). Vitamin G: effects of green space on health, well-being, and social safety. BMC public health, 6(1), 149. https://doi.org/10.1186/1471-2458-6-149
26. Thomas C.C., Huber C.C., Koontz L. (2015). 2014 National park visitor spending effects: economic contributions to local communities, states, and the nation (No. NPS/NRSS/EQD/NRR—2015/947). National Park Service.
27. Doran J.W., Safley M. (1997). Defining and assessing soil health and sustainable productivity. CAB International 1-28. Retrieved from: https://www.ars.usda.gov/research/publications/publication/?seqNo115=78601
28. Koenig R., Isaman V. (2010), Topsoil Quality Guidelines for Landscaping. Gardening. Paper 15. Retrieved from: https://digitalcommons.usu.edu/extension_curgarden/15

29. Laster K.J., Arnwine D.H. Denton G.M., Cartwright L.K., Cochran, R.E. (2014). The status of water quality in Tennessee. Retrieved from: https://www.tn.gov/content/dam/tn/environment/water/documents/wr_wq_report-305b-2014.pdf
30. Lehman C.L., Tilman D. (2000). Biodiversity, stability, and productivity in competitive communities. The American Naturalist, 156(5), 534-552. https://doi.org/10.1086/303402
31. Tilman D., Reich P.B., Knops J.M. (2006). Biodiversity and ecosystem stability in a decade-long grassland experiment. Nature, 441(7093), 629-632. https://doi.org/10.1038/nature04742
32. Oliver T.H., Heard M.S., Isaac N.J., Roy D.B., Procter D., Eigenbrod F., ... Proença V. (2015). Biodiversity and resilience of ecosystem functions. Trends in ecology & evolution, 30(11), 673-684. https://doi.org/10.1016/j.tree.2015.08.009
33. Haines-Young R., Potschin M. (2010). The links between biodiversity, ecosystem services and human well-being. Ecosystem Ecology: a new synthesis, 1, 110-139. https://doi.org/10.1017/CBO9780511750458.007
34. Tennessee Wildlife Resources Agency (TWRA), Tennessee State Wildlife Action Plan Team. Tennessee State Wildlife Action Plan 2015. Retrieved from: http://www.tnswap.com/pdf/2015swap.pdf
35. Pimentel D., Zuniga R., Morrison D. (2005). Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological economics, 52(3), 273-288. https://doi.org/10.1016/j.ecolecon.2004.10.002
36. McKinney M.L., Lockwood J.L. (1999). Biotic homogenization: a few winners replacing many losers in the next mass extinction. Trends in ecology & evolution, 14(11), 450-453. https://doi.org/10.1016/S0169-5347(99)01679-1
37. Hulme P.E. (2014). Invasive species challenge the global response to emerging diseases. Trends in parasitology, 30(6), 267-270. https://doi.org/10.1016/j.pt.2014.03.005
38. Andersen M.C., Adams H., Hope B., Powell M. (2004). Risk assessment for invasive species. Risk Analysis: An International Journal, 24(4), 787-793. https://doi.org/10.1111/j.0272-4332.2004.00478.x
39. Gregory R.D., van Strien A. (2010). Wild bird indicators: using composite population trends of birds as measures of environmental health. Ornithological Science, 9(1), 3-22. https://doi.org/10.2326/osj.9.3
40. Sánchez-Bayo F., Wyckhuys K.A. (2019). Worldwide decline of the entomofauna: A review of its drivers. Biological conservation, 232, 8-27. https://doi.org/10.1016/j.biocon.2019.01.020
41. World Wildlife Foundation. (2018). Living Planet Report 2018. Retrieved from: https://c402277.ssl.cf1.rackcdn.com/publications/1187/files/original/LPR2018_Full_Report_Spreads.pdf
42. Whelan C.J., Wenny D.G., Marquis R.J. (2008). Ecosystem services provided by birds. Annals of the New York academy of sciences, 1134(1), 25-60. https://doi.org10.1196/annals.1439.003

43. Díaz S., Fargione J., Chapin III F.S., Tilman D. (2006). Biodiversity loss threatens human well-being. PLoS Biol, 4(8), e277. https://doi.org/10.1371/journal.pbio.0040277
44. Etnier D.A., Starnes W.C. (1993), The Fishes of Tennessee. University of Tennessee Press. Retrieved from: https://trace.tennessee.edu/utk_utpress/2/
45. Bond N.R., Lake P.S., Arthington A.H. (2008). The impacts of drought on freshwater ecosystems: an Australian perspective. Hydrobiologia, 600(1), 3-16. https://doi.org/10.1007/s10750-008-9326-z
46. Gleick P.H. (2015). Impacts of California's ongoing drought: hydroelectricity generation. Oakland, Calif.: Pacific Institute. Retrieved January, 21, 2016.
47. Strzepek K., Yohe G., Neumann J., Boehlert B. (2010). Characterizing changes in drought risk for the United States from climate change. Environmental Research Letters, 5(4), 044012. doi:10.1088/1748-9326/5/4/044012
48. Lee J.H., Kim C.J. (2013). A multimodel assessment of the climate change effect on the drought severity–duration–frequency relationship. Hydrological Processes, 27(19), 2800-2813. https://doi.org/10.1002/hyp.9390