RESEARCH & DEVELOPMENT

Economic Analysis of Vegetation Management Practices

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16. Abstract The purpose of this study was to conduct a thorough evaluation of the mechanical, chemical and cultural components of all vegetation management operations and their governing organizational structures to determine cost-effective practices and efficient administrative procedures and structures. The research problem being investigated is how to reduce costs associated with vegetation management as well as how to administer the vegetation management program within the NCDOT more effectively. The research design used was mixed methods, with a quantitative cost analysis, as well as qualitative interviews, peer state comparisons, and gathering relevant background information. The major conclusion that resulted from this study is that it would be cost-effective to replace one mowing cycle by one PGR application cycle, which would result in an estimated $2.5 million in yearly savings.		
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Executive Summary

Background

The current study was conceptualized to document and analyze effective coordination of turf management by NCDOT inclusive of the Road Environmental Unit and the Roadside Environmental and Roadway Maintenance Division staff. This study was completed by researchers from North Carolina State's (NCSU) Institute for Transportation Research and Education (ITRE) and State University of New York at Brockport with funding from the NCDOT.

Process

The duration of this research project was two years. The approach for this research includes mixed methods, including a quantitative cost analysis as well as qualitative interviews, gathering relevant background information, and peer state comparisons. The data was collected from the NCDOT, from online searches, and interviews were completed either over the telephone/email or in person at various locations across North Carolina.

First, a literature review and a document review of pertinent states was completed (i.e. Alabama, Kentucky, North Carolina, Texas). Next, a cost analysis was completed using NCDOT data in order to identify areas for potential cost savings, specifically relating to the mowing and PGR data. Seventeen interviews were completed with NCDOT Roadside Environmental staff. A benchmarking analysis was completed by comparing NCDOT vegetation management practices to those of three other states (Alabama, Kentucky and Texas).

Research Findings

Generally, it appears that NCDOT operates an efficient and cost effective roadside vegetation management system and utilizes many best practices identified in this study. This research concluded with seven findings as described below.

Two findings come from peer state analysis:

1. NCDOT's annual budget for roadside vegetation management is comparable to Texas, with Alabama and Kentucky reporting less extensive road networks and corresponding lower budgets in comparison to North Carolina.

2. The literature review and peer state interviews lent support for including eco-regional approaches into integrated vegetation management plans and implementing regular, mandatory training for vegetation management professionals.

   The remaining five findings followed from a review of the literature, interviews, data collection, cost analysis, and document review.

3. Replacing one mowing cycle with an additional PGR application cycle on all systems may result in cost savings of $2.5 million annually. The most significant savings are associated with the implementation of PGR applications on secondary roads. That may result in a savings of $1.4 million per year primarily from reduce mowing costs.

4. The coordination of PGRs applications and mowing is critical for maximizing the benefits of PGRs. The passage of House Bill 97 consolidated responsibilities for vegetation management from Roadside Maintenance and Roadside Environmental Units into one, with responsibility for all vegetation management practices administered solely by Roadside Environmental staff.

5. While secondary roads are mowed more frequently, interstates and primary roads are more likely to be applied with PGR applications. In addition, March through July are the most common times that PGRs are applied, with most division staff reporting that applying PGRs is associated with one less mowing cycle, with some believing applying PGRs can save two mowing cycles.

6. Inconsistencies were found between the purchase order data and the NCDOT fiscal data, as well as between fiscal years. This suggests potentially inconsistent cost reporting.

7. Division staff cited the following barriers to increasing the coverage and number of PGR applications: too few personnel, budgetary restrictions, not enough equipment, and having a limited time window for successful PGR applications.

Recommendations

Five recommendations follow from this research and correspond to the findings.

1. Consider the use of one additional PGR application cycle across all systems, including secondary, to accrue potential cost savings.

2. Continue to monitor the effective coordination between mowing and PGR applications, with the help of the Roadside Vegetation Management Tool to monitor costs of vegetation management practices.

3. Additional consideration should be given to effectively integrate eco-regional approaches into vegetation management practices as described by the benchmarking with peer states analysis as well as the literature review.

4. Standardize cost reporting practices for mowing and PGR applications. This could help make NCDOT fiscal data more consistent across fiscal years. For example, one division representative mentioned during interviews that in FY 2015, they used function code 2908 (“Brush and Tree Control”) a lot to report turf management, rather than function code 2904 (“Turf Management”). Standardizing these reporting practices can facilitate a more precise analysis in the future.

5. Consider ways to mitigate the most commonly mentioned barriers to the increased application of PGRs in interviews with NCDOT staff. An increase in staff and equipment, as well as additional contracted services, are options to be considered.

Further research may identify other methods to manage different types of turf in order to maximize cost-effectiveness and efficiency.

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Introduction

Vegetation growth along highways is a significant maintenance issue for transportation departments, since poorly managed vegetation can have adverse impacts on roadways due to increased risks to traffic and premature deterioration of the road system infrastructure. In addition, budget cuts make it challenging to maintain vegetation along roadways with fewer staff and limited resources. Furthermore, public awareness of environmental impacts associated with vegetation management has given rise to the development of Integrated Roadside Vegetation Management Programs (IRVMPs) across the United States. The North Carolina Department of Transportation (NCDOT) defines the IRVMP as "a decision making and quality management process for maintaining roadside vegetation that integrates… [the] needs of local communities and highway users, knowledge of plant ecology processes, design, construction, and maintenance considerations, monitoring and evaluation procedures, government statutes and regulations, and technology with cultural, biological, mechanical, and chemical pest control methods to economically manage roadsides for safety plus environmental and visual quality" (p. 1).

The NCDOT has also adopted an IRVMP, but its implementation can be significantly enhanced through the study of costs attributable to each practice associated with vegetation management. Comprehensive cost and effectiveness data are not readily available for practices such as mowing, herbicidal applications, tree trimming, brush control etc. especially when broken down by different types of vegetation (e.g. trees, weeds, brush and different types of turf grasses such as fescue, zoysia, etc.).

The need for data-based cost-effectiveness measures is imperative because in North Carolina, the legislature has been placing an emphasis on needs-based budgeting. This further underscores the requirement for a complete understanding of current vegetation management procedures being employed by NCDOT, as well as the inter-organizational relationships that are currently in place to manage them across the state's 14 divisions. In addition, it is also imperative to have reliable cost and effectiveness data associated with each vegetation management practice. It is only with this knowledge that NCDOT can develop and enact cost-effective and need-based vegetation management budgets that are grounded in reliable data.

In line with this identified need, the goal of this study is to complete a thorough evaluation of the mechanical, chemical and cultural components of vegetation management operations related to turf and woody vegetation in order to determine cost-effective practices as well as efficient administrative procedures and structures.

Research Approach

The methodology for this study included gathering and analyzing data on various turf types and vegetation management practices as well as cost-effectiveness data that were obtained by completing in-person as well as emailed interviews with 14 roadside environmental engineers, interviews with NCDOT vegetation management administrators, and an interview with a vegetation management professional at Duke Energy. A literature review and a document analysis (e.g. NCDOT website) were also completed. Appendix A displays a list of interviewees and Appendix B shows the interview questions. As a part of the cost analysis, NCDOT cost data was utilized to construct a NCDOT Cost Effectiveness Tool and to compare costs of mowing and herbicidal applications per shoulder mile, as well as per cycle per shoulder mile. NCDOT division contracts were also analyzed to gather relevant data regarding organizational structure and vegetation management procedures.

Literature Review

In the United States, there are over 17,000,000 acres of roadside that need regular vegetation management. The NC road system alone has one of the most extensive highway systems in the United States, with 80,000 total miles of road (NCDOT, 2017). As stated in the introduction, vegetation management practices have to balance a plethora of factors such as ensuring the long-term performance of highways, minimizing environmental impact, and operating with decreasing budget resources. Traditionally, roadside vegetation management has been divided into two separate approaches: mow and apply pesticides or encourage native growth. These two approaches are also referred to as agricultural (Harper-Lore, Johnson & Skinner 2007) and eco-regional (Harper-Lore et al., 2013), respectively. More recently, in response to the complexities surrounding vegetation management, roadside managers across the United States have begun to utilize an Integrated Roadside Vegetation Management Program, which holistically combines traditional vegetation management approaches such as mowing and pesticide application, with eco-regional approaches. Two excellent references on the subject are Berger (2005), which includes a compendium of best practices across the country, and also the Integrated Roadside Vegetation Management Technical Manual available from the University of Northern Iowa (Brandt, Henderson, & Uthe, 2015).

There are several common ways in which vegetation can be controlled on roadsides including cultural, biological, mechanical, chemical, and combinations thereof. Common methods include hand cutting, mowing, and herbicide application (Jackson & Finley, 2007; Johnstone, 2008). Herbicides may be applied in a variety of ways including basal bark, basal soil, cut stump, foliar, hack and squirt, and stem injection. Another class of pesticides, plant growth regulators, commonly referred to as PGRs, may also be used to suppress turf grasses in order to reduce the intensity of management needed. Timely plant growth regulator applications can save significant time and money put towards mowing.

Woody vegetation must also be managed on roadsides. Many woody species produce stump sprouts including common North Carolina hardwoods such as black locust (*Robinia pseudoacacia*), red maple (*Acer rubrum*), sweetgum (*Liquidambar styraciflua*), yellow poplar (*Liriodendron tulipifera*), etc. Stump sprouts are a common occurrence after mechanical cuts leave a hardwood stump. Cut stump herbicide applications can be used to combat this problem (Haymond & McNabb, 1994) or intensive and indefinite mowing may be required. One major advantage to this technique is that it works on invasive hardwoods and woody vine species of various sizes with the exception of stems less than half an inch diameter.

Finally, it is also important to note that absent efficient organizational structures and clear and well managed processes, even the cost effective solutions are doomed to suffer, leading to degraded organizational performance (Nair, 2006). Therefore, it is important that the development of cost-effective vegetation management strategies be accompanied with corresponding recommendations about efficient organizational structures and procedures to implement them.

Methods for Vegetation Management

Methods used for vegetation management include the following categories: (1) mechanical, (2) chemical, (3) cultural, (4) biological (Gover, Johnson & Kuhns, 2007), and (5) indirect strategies (Bennett, n.d.).

Mechanical. Mechanical approaches include mowing, string trimming, cat excavation, mechanical mulchers, brush cutters, and other mechanized forms of weed control (Bennett, n.d.). Tillage, ripping, and subsoiling are also included in this definition (Bennett, n.d.), as well as grubbing (Gover et al., 2007). This method involves the use of mechanical equipment to crush, chop, or break apart tree saplings and brush, which leaves behind organic matter from plants on the ground (Bennett, n.d.). Gover et al. (2007) recommend cutting turf between 4 to 8 inches from the ground in order to minimize stress to turf species, which will allow them to more effectively compete against the weeds, stabilize the soil, and enhance the effectiveness of herbicide applications. If turf is mowed too soon following an herbicide application, this could make the herbicide application less effective, particularly if the chemical treatment has not yet had a chance to move into the target weed species (Gover et al., 2007). It is recommended to use PGRs following mechanical work in order to prevent the species from growing back; for example, following either trimming branches or cutting a tree down, the application of PGRs prevents it from growing back (Gover et al., 2007). Mulching and brush cutting helps to retain organic matter and soil moisture, which facilitates growth and health in desirable plant species (Bennett, n.d.).

Chemical. Chemical approaches to vegetation management can be classified into several different categories, including selective/non-selective, pre-emergent/post-emergent, foliar-applied/soil-applied, and based upon the type of plant species targeted (Gover et al., 2007). Chemicals used are either selective or non-selective. Selective chemicals damage or kill unwanted plants while allowing desirable plants to remain (PSCAS, 2016). Examples of selective herbicides include triclopyr and some plant growth regulators. In contrast, non-selective chemicals kill or damage any plants in a given area without specifically targeting the species that is considered to be a nuisance (PSCAS, 2016). An example of a non-selective herbicide is glysophate (i.e. Round Up) (PSCAS, 2016). Duke (1990) described the mechanisms of action of herbicides, and wrote that many types of herbicides act through the inhibition of photosynthesis, while others inhibit lipid synthesis, particularly with monocot weeds (e.g. Fescue). According to Duke (1990), “in addition to site of action structure-activity relationships, herbicide structure and chemical properties also strongly influence absorption, translocation, bioactivation, and environmental stability” (p. 1). In other words, there are a variety of factors to consider regarding the effectiveness of herbicidal applications.

Chemical approaches can also be divided into pre-emergent or post-emergent categories. Pre-emergent chemicals are applied prior to the growth of the plant, while post-emergent chemicals are applied following plant growth (NCDOT Roadside Environmental Unit, n.d.; PSCAS, 2016). An example of a pre-emergent herbicide includes plant growth regulators. An example of a post-emergent herbicide is glysophate (i.e. Round Up).

Herbicides can also be classified based upon whether they are foliar- or soil-applied. According to Penn State College of Agricultural Sciences (2016), “post-emergence herbicides are usually foliar applied, whereas pre-emergence herbicides are soil applied” (p. 1). Of course, there are also different herbicides that would be appropriate depending upon the type of plants dealt with (e.g. wooded species and broadleaf control chemicals).

Chemical sprayers are often used to apply herbicides to manage roadside vegetation over large areas and can include truck sprayers and handheld sprayers, among others (Holland, 2013). The term "surfactant" is a shortened version of the term "surface active agent," and refers to chemicals added to herbicides to increase their effectiveness (Lincoln County Noxious Weed Control Board, n.d.). Specifically, surfactants used for vegetation management along with herbicides work by spreading, sticking, and/or penetrating the herbicide into the plant, as well as by making it more difficult for weather conditions to prevent the uptake of the chemical (Lincoln County Noxious Weed Control Board, n.d.).

CSU Agricultural Sciences (2014) found that the application of PGRs resulted in a reduced amount of clipping and mowing needed. In addition, PGRs were associated with an improved quality of turf species, reduced costs of maintenance, and the reallocation of labor (CSU Agricultural Sciences, 2014).

Biological. Biological approaches to vegetation management involve introducing an advantageous organism to an area in order to target an undesirable organism (Gover et al., 2007). This approach to vegetation management includes the introduction of a disease, fungus, or insect to control weeds (Bennett, n.d.; Gover et al., 2007). Biological approaches usually involve the reduction in the mass of targeted plants rather than completely destroying them, and it is important to coordinate biological control efforts with the North Carolina Department of Agriculture (Bennett, n.d.).

Indirect/Cultural. Indirect approaches to vegetation management, also referred to as cultural methods, involve applying principles of weed ecology to modify the environment to make it less amenable to undesirable plant species (Bennett, n.d.). Gover et al. (2007) noted that "a well-established groundcover is the best line of defense against weed and brush encroachment" (p. 2), and that the revitalization of turf should be completed following erosion or roadside maintenance activities. This means ensuring that topsoil is still present and that it is not smoothed from the vegetation management equipment (Gover et al., 2007). Incorporating fertilizer into apply applications, as well as mowing high, can also help to facilitate the growth of desirable vegetation (Gover et al., 2007). Cultural approaches to vegetation management "enhance the growth of desirable vegetation, or prevent weed growth and establishment" (Gover et al., 2007, p. 1). This approach could involve the introduction of more shade to a particular area and/or the application of a thick layer of organic matter, since many undesirable plant species have a harder time growing in shade and organic material (Bennett, n.d., p. 7). Thoroughly cleaning and sanitizing equipment between locations, as well as utilizing soil from areas without weeds, are two ways to prevent weed establishment (Bennett, n.d.). Bennett noted that indirect approaches to vegetation management can be cost-effective.

Integrated Roadside Vegetation Management Programs (IRVMPs). Integrated Vegetation Management approaches involve the coordination of a multi-faceted program to control problematic plant species (Gover et al., 2007). For example, the Idaho Transportation Department's IRVMP involves the consideration of mechanical, biological, cultural, and chemical methods of control based upon ecological impacts, impacts to human health, cost-effectiveness, and feasibility considerations (2013). The goal of the Idaho IRVMP is to "[provide] safe and reliable transportation, [maintain] infrastructure investments, [operate] within budget and personnel limitations, and [to minimize] environmental impacts" (ID Transportation Department, 2013, p. 1). Similarly, the Pennsylvania DOT involves four components – mechanical, cultural, biological, and chemical – and it is noted that the chemical approaches taken under their Integrated Vegetation Management Plan is the most cost-effective (Gover et al., 2007). North Carolina currently has an IRVMP in which "decisions to utilize herbicides are made after cultural or biological control methods have been evaluated" (NCDOT Roadside Environmental Unit, n.d.). IRVMPs, as illustrated by the two examples listed, typically involve evaluating various methods to vegetation management to use the most effective approach with the least adverse environmental impact.

Economic Analyses of Roadside Vegetation Management

According to an analysis of the PennDOT Herbicide Program Overview, their herbicide program is the most cost-effective element of PennDOT's vegetation management program as compared to mechanical, cultural, and biological techniques (Gover et al., 2007). While herbicide treatments are most often used by PennDOT, herbicidal treatments are most effective when used in tandem with other approaches for vegetation management (Gover et al., 2007). In addition, it is not recommended to apply herbicides right before or after mowing (Gover et al., 2007). A combination of herbicides is typically applied depending on the objective of the program, and product cost is one element taken into consideration when assigning a Cost Function Code (Gover et al., 2007). Selective weed and brush control can be used to control non-woody broadleaf weeds and brush with just one application (Gover et al., 2007).

In a comparison of roadside management practices in Washington, the impacts of herbicide use on cost was studied following public concerns of associated environmental impacts (Maintenance and Operations Division, 2003). The WADOT uses herbicides along with mechanical, manual and horticultural methods to manage vegetation along the roadsides (Maintenance and Operations Division, 2003). In responding to public concerns, this study evaluated the cost to manage roadsides without the use of herbicides. Specifically, the current costs with herbicides were compared to the costs without the use of herbicides for four different categories, including (1) shoulder maintenance, (2) noxious weed control, (3) tree, brush and nuisance weed control, and (4) the initial purchase of new equipment (Maintenance and Operations Division, 2003). For shoulder maintenance, the annual costs for a vegetation management plan including herbicides was estimated to be $979,217 (herbicides: $76,650; shoulder mowing: $204,400; shoulder pulling with and without the guardrail: $698,167) and the costs for a vegetation management plan without herbicides was estimated to be $2,151,422 (shoulder mowing: $511,000; mowing by hand around guardrail: $287,895; shoulder pulling with and without the guardrail: $1,352,527).

Herbicides are sometimes the only management option that also complies with WA state laws for ridding roadsides of noxious weeds; therefore, the costs were assumed to be the same for the current year and the proposed maintenance without herbicides (Maintenance and Operations Division, 2003). The current annual costs with herbicides for tree, brush, and nuisance weed control were $406,068, with costs estimated to be $605,433 without herbicides (Maintenance and Operations Division, 2003). The initial purchase of new equipment necessary to accomplish the additional mowing if herbicides are not used is around $1,303,000 (Maintenance and Operations Division, 2003). The additional annual costs associated with using non-herbicidal methods is estimated to be $1,371,570, and when combined with the costs to purchase new equipment, the projected initial cost would be $2,674,570 to transition from a vegetation management plan to one without herbicides (Maintenance and Operations Division, 2003). Therefore, a vegetation management program including herbicides as well as other approaches is more cost-effective when compared with a vegetation management program without herbicides.

In another report completed in response to public concern surrounding the harm of herbicides on non-targeted plants as well as aesthetics of an area, an assessment of mechanical and herbicidal methods of managing roadside vegetation was published by the Texas DOT (Brennan, 2012). Mechanical methods of removal for roadside vegetation were estimated to cost between $1000 and $3000 per mile of road side treated, while herbicidal/chemical approaches of removal for roadside vegetation were estimated to cost around $140 per mile of road side treated (Brennan, 2012). Therefore, mechanical methods cost about 11 times more than herbicidal methods (Brennan, 2012). The report did not estimate the total cost of each method because they are based on cost per mile, which can vary year to year. Due to a tight budget and the findings listed above, the TXDOT has begun to consider the use of herbicides as frequently as possible (Brennan, 2012). Similarly, Louisiana found that it was best to use herbicides, unless there is an immediate safety issue, in which case, mechanical methods are more appropriate (Brennan, 2012).

In one study focusing on alternative approaches to herbicides and mechanical methods in managing roadside vegetation, the cost of citric acid, clove oil, corn gluten meal, and pelargonic acid were estimated (Barker & Prostak, 2009). It was found that the cost of alternative herbicides was higher than using conventional herbicides; retail prices and labor costs were more expensive because alternatives had to be applied three or more times per year (Barker & Prostak, 2009). Additionally, the cost of using bark or woodchip mulch was more expensive than mowing, conventional and alternative herbicides, although it was most effective in weed prevention (Barker & Prostak, 2009). In line with this finding, Bennett (n.d.) noted that while non-chemical approaches to vegetation management may be viable, chemical applications are generally more cost-effective in comparison. In addition, particular species may be next to impossible to control without chemical applications (Bennett, n.d.). PGRs are associated with a reduction in fuel, machinery, and labor costs (CSU Agricultural Sciences, 2014).

In another study that compared the cost-effectiveness of vegetation management plans with and without chemical treatments, it was found that there were higher indirect costs for mechanical and thermal control methods than for herbicide applications (Nowak et al., 2005). In addition, all non-herbicide alternatives were less effective than herbicides, with the exception of mulches, geotextiles, and solidifiers (Nowak et al., 2005). Through the creation of a cost-effectiveness matrix, it was found that none of the non-herbicidal alternatives were as cost effective as the conventional herbicide treatments (Nowak et al., 2005). In some categories, Nowak et al. (2005) found that mulches, solidifiers and bioherbicides were more beneficial and cost-effective when compared to herbicides, although the overall conclusion of the report found conventional herbicides to be more cost effective when compared to non-herbicide treatments.

In a case study focusing on expenses associated with vegetation management approaches with and without herbicides in Hillsborough County, Florida, mechanical mowing was estimated to be $60/acre, and $2,340,000/year with six mowing cycles (Colorado State University Agricultural Sciences, 2014). In contrast, herbicide applications were estimated at $35/acre and $1,235,000/year with two mowing cycles and two herbicide applications (Colorado State University Agricultural Sciences, 2014). The total estimated savings per year associated with the use of herbicide in tandem with mowing amounted to $1,105,000 (Colorado State University Agricultural Sciences, 2014). Overall advantages found by switching to herbicide application with two mowing cycles included significant cost savings, reduced shoulder deterioration, a decrease in complaints by citizens, and improved aesthetics and labor efficiency (Colorado State University Agricultural Sciences, 2014).

The California DOT explored alternatives to herbicide applications and found that the cost per volume of the natural products was lower than herbicides, but with more frequent applications, the natural products turned out to be more expensive (Young, 2003). Natural-based herbicide products most easily substituted for the traditional herbicides, but they damaged the vegetation and required higher volumes of more frequent applications (3-5) to even be comparable to the synthetic standard herbicide, glyphosate (i.e. Roundup) (Young, 2003). Although it was noted that the authors were unable to determine the comparable price of these alternatives to mowing, the report conclusion was that traditional synthetic herbicides are more effective than natural based products on the market at that time (Young, 2003).

In a study of vegetation management methods used along roadsides completed by the Indiana DOT, it was found that replacing one mowing cycle with one herbicide application results in a 40% cost reduction (Herold, Lowe & Dukes, 2013). The potential of using native plants to reduce maintenance costs was also studied, but the findings were inconclusive, due to a drought occurring at the time of the study. The report also concluded that mowing is less cost efficient than herbicidal applications, with mowing estimated to be $64/mile, and chemical applications estimated to be $36/mile, a cost savings of $28 per mile (Herold et al., 2013). The study authors also noted that herbicide applications are more effective at weed reduction in comparison with mowing. Herold et al. (2013) described mowing as "the most hazardous form of vegetation management because the slow speed and frequency of mowing puts maintenance crews near traffic for extended periods of time" (p. 9).

Weed management programs that use a combination of methods can be more cost efficient and effective (Cherry, 2003). Mechanical control methods require repetition (Cherry, 2003). Although not popular with the public, herbicides have proven to be both cost efficient and effective (Cherry, 2003). One way to help cut costs and decrease the amount of herbicides used would be to dilute the chemical to allow it to go even further, which agencies have determined to still be effective (Cherry, 2003). Too many chemicals can sometimes harm desirable plants, as well as noxious weeds, so this less concentrated formula helps with that as well (Cherry, 2003). Iowa uses native grasses, wildflowers and legumes to reseed right-of-way, which allows for more aesthetically pleasing roadsides and greater cost reduction; these plant species do not require frequent mowing (Cherry, 2003). It is important to avoid unnecessary mowing because it is costly and can damage the roadside slopes (Cherry, 2003).

The “Integrated Weed Management Plan: A Handbook for Owners and Managers of Lands with Natural Values” provided information about different approaches to vegetation management; a major conclusion of this report was that mowing and cutting rarely kills weeds (Colorado Department of Agriculture, 2000). It was also found that mowing must be frequently repeated to maintain control (Colorado Department of Agriculture, 2000). However, cutting can be very effective for treating some types of trees and shrubs when used with herbicides (Colorado Department of Agriculture, 2000). Mowing and cutting are associated with particular disadvantages that are not associated with herbicides; for example, inaccessible areas such as ones that are too rocky or steep may not be feasible with mechanical methods (Colorado Department of Agriculture, 2000). The estimates above from the different states for costs and savings associated with the application of herbicides as a way are summarized in Table 1.

Table 1 *Cost savings by state associated with switching to an integrated vegetation management plan in lieu of one without the use of herbicides.*

State	Estimate of Costs/Savings through application of PGRs
Indiana	The Indiana Department of Transportation (2013) estimated the cost per mile for mowing to be $64, as opposed to $36 per mile for herbicidal applications. This shows an estimated savings per mile of $28 if an integrated vegetation management plan, including herbicides, is used as opposed to one without herbicides.
Florida	CSUAS (2014) estimated the cost per acre for mowing to be $60, with an annual cost of $2,340,000 with an assumption of six mowing cycles. In contrast, the estimated cost per acre for herbicide applications was $35, with an annual cost of $1,235,000. In line with these estimates, the projected savings associated with integrating herbicidal applications with mowing cycles is $1,105,000.
Texas	Brennan (2012) compared the costs per mile for mechanical and chemical approaches to vegetation management, and found mechanical methods to cost around 11 times more than chemical approaches. Specifically, the cost for mechanical approaches was estimated to be $1,000-$3,000 per mile, and the cost for herbicidal applications was around $140 per mile (Brennan, 2012).
Washington	The Washington Maintenance and Operations Division (2003) compared costs between mechanical only and mixed mechanical and chemical approaches to vegetation management with a similar result. Specifically, annual costs for a plan without herbicides would be $2,151,422, and a vegetation management plan including herbicides would be $979,217; this reflects an estimated cost savings of $1,172,205 annually if herbicidal applications are included.

NCDOT Roadside Environmental Operations and Organizational Structure

The mission of the NCDOT is "*to provide roadside elements for a statewide highway system that are safe, environmentally sound, attractive and responsive to the public's needs*" (n.d.). The average annual budget for vegetation management activities is around $62 million. Figure 1 outlines the organizational structure of the NCDOT Roadside Environmental Unit (NCDOT Roadside Environmental Unit, n.d.), Figure 2 shows a map of the divisions, and Table 2 displays the NCDOT counties within each of the 14 divisions.

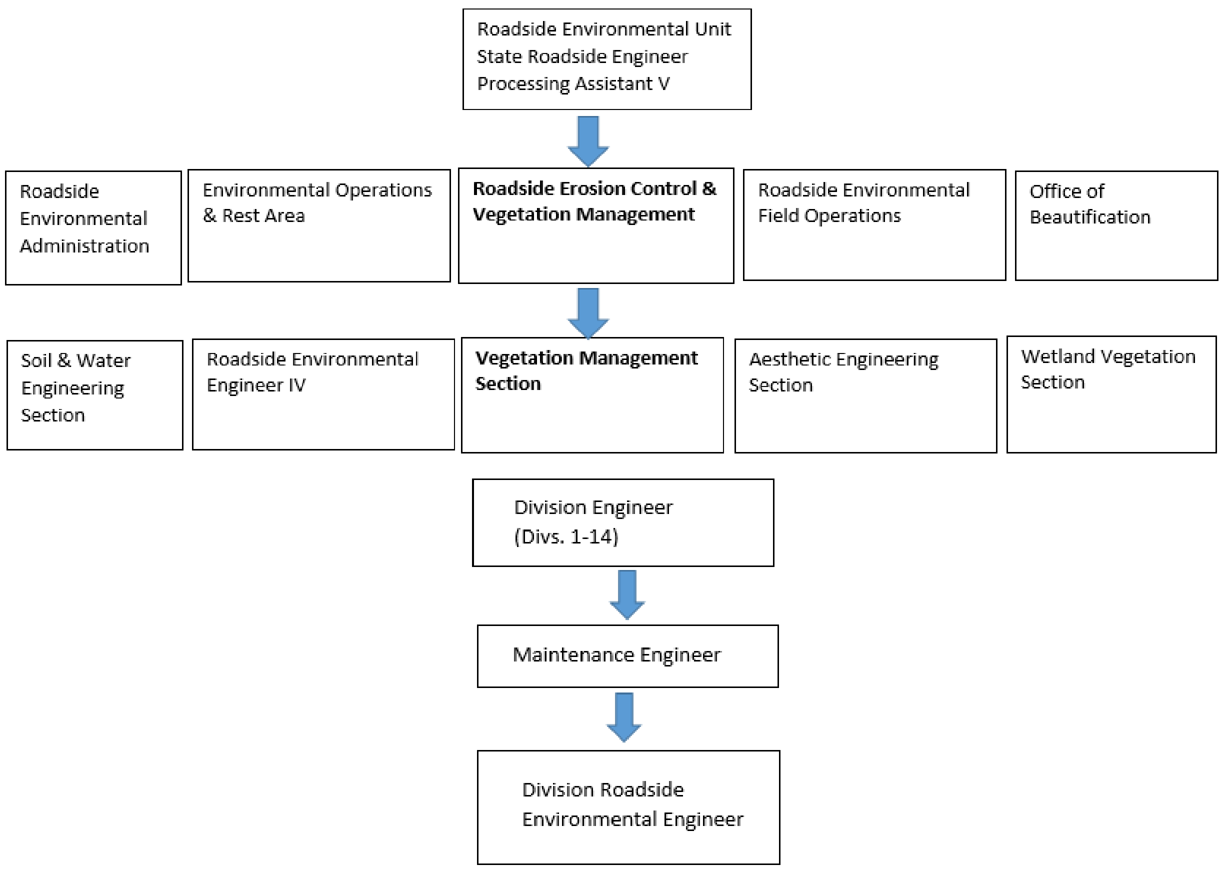

Figure 1 *NCDOT Roadside Environmental Unit organizational structure*.

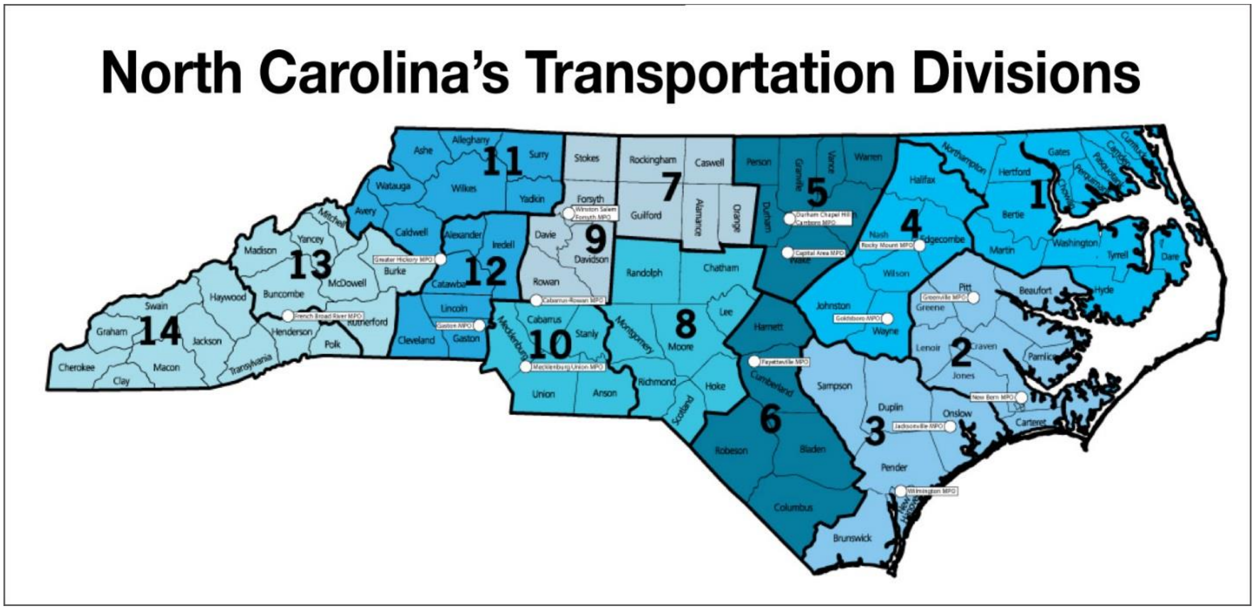

Figure 2 *NCDOT Division Map*.

Table 2 *The number of counties in each NCDOT division, displayed by division numbers. This table corresponds to Figure 2 (above), the NCDOT Division Map.*

No. of counties	Divisions
5	6, 7, 9, 10
6	3, 4, 12
7	5, 13
8	2, 8, 11
10	14
14	1

Previously, the NCDOT Roadway Maintenance staff in each Division was in charge of administering contract mowing operations and Roadside Environmental Division staff was in charge of herbicidal applications. In some instances, there was a lack of coordination until House Bill 97 was passed, which mandated the transfer of responsibility for vegetation management within the DOT from the Roadside Maintenance Unit to the Roadside Environmental Unit (Session Law 2015-241, section 29.9A). Now, Roadside Environmental staff is in charge of both mowing and herbicidal applications. All divisions have undergone this legislatively mandated change, except for division 13. Within Division 13, Roadside Maintenance is still in charge of mowing while Roadside Environmental is responsible for applying herbicides. According to Division 13, there are 25 roadside environmental positions in the division with six vacancies, although there were previously 42 positions. Division 13 roadside environmental has four crews focusing on vegetation management, including the following focus areas: two crews focusing on erosion control, one crew focusing on plant bed maintenance, and one crew whose responsibility it is to apply herbicides and facilitate wildflower establishment.

Figure 3 below depicts the organizational structure of division 9, and is fairly typical of each NCDOT roadside division. The division roadside engineer oversees all aspects of the vegetation management program, including the three engineering technicians currently employed with the division. According to one interviewee, “roadside technicians [in charge of particular districts] are used to inspect mowing, tree removal, fully operated rental, litter removal, and long arm mowing in their respective districts. Other duties may include inspecting enhancement projects and [selective vegetation removal] work as needed.” The engineering technician in charge of rest areas is responsible for maintaining rest areas as well as facility maintenance. It is also noted that another engineering technician position has been proposed. The proposed position “would be used to assist the roadside engineer, be the lead inspector on enhancement projects and contract plant bed maintenance contracts, and help coordinate responsibilities of other technicians. Additional duties would include assisting the engineer in mapping assets, [Highway Construction and Materials System] entry, inspecting storm water devices and [selective vegetation removal] work as needed.”

The division roadside environmental engineer also oversees the transportation supervisor, who is in charge of all three types of vegetation management crews: (1) herbicides, (2) plant maintenance, and (3) tractor crews. The herbicide crew consists of five people and is responsible for applying plant growth regulators, broadleaf weed control, invasive weed control, brush control, applying re-emergent to plant beds, maintaining wildflower programs, maintaining vegetation around bridges, and weed control around guard rails. The plant maintenance crew consists of five people and is responsible for mowing, tree cutting, maintenance at rest areas, maintenance of division offices, overlook maintenance, mowing around wildflower beds, installing plant beds, and mulching, among other tasks. Finally, the tractor crew consists of four people and is responsible for “bush-hogging, seeding and mulching, planting wildflowers, right-of-way fence repair, and mowing.” It is also noted that a position for an office assistant has been proposed to assist with the Adopt-a-Highway program, as well as paying invoices and other secretarial duties, like answering telephones.

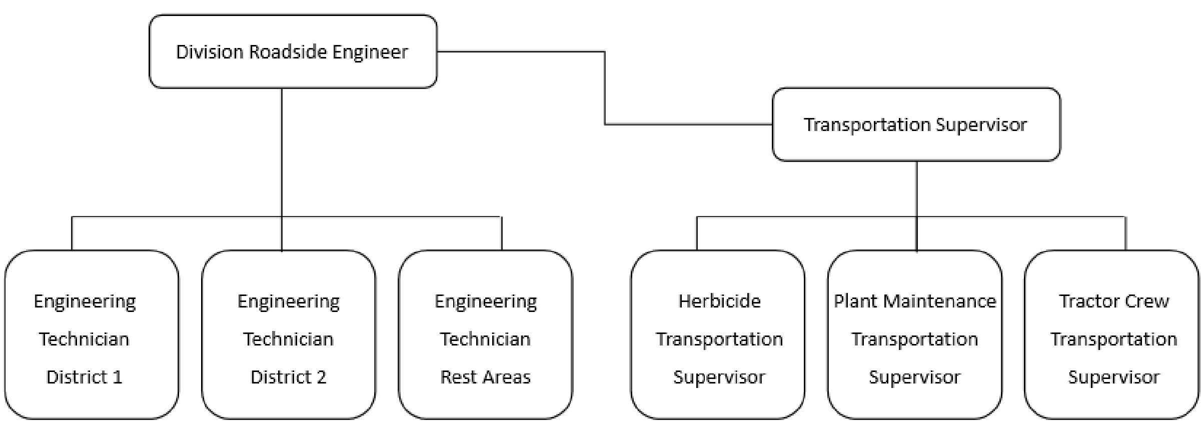

Figure 3 *General NCDOT Division Organizational Structure. Information provided by Div. 9.*

Since the organizational structure has changed, the same amount of work is now accomplished with fewer people. According to Division 11, there are 22 staff involved with vegetation management in their division. These 22 staff include, among others, include the following: six inspectors who monitor the work of contractors (i.e. three turf mowing inspectors and three long arm mowing inspectors) two who focus on herbicide applications, one on the seed crew, and one who focuses on planting and plant bed maintenance. It was also mentioned during interviews that broadleaf weed control is applied together with plant growth regulators.

The NCDOT Roadside Environmental Unit addresses vegetation management as follows:
(1) turf management, (2) woody vegetation, (3) weeds, (4) wildflower weed control, (5) noxious and aquatic, and (6) Selective Vegetation Removal. Our study focuses on turf management and woody vegetation.

Within the turf management section, there are five maintenance programs: (1) plant growth regulators (PGR), (2) Warm Season Release, (3) seed head control, (4) broadleaf weed control, and (5) annual grass control. Table 3 displays descriptions of the turf management maintenance programs from the NCDOT Roadside Environmental Unit website (n.d.).

Table 3 *Turf management maintenance program descriptions verbatim from the NCDOT Roadside Environmental Unit website (NCDOT Roadside Environmental Unit, n.d.).*

Maintenance Program	Description
Plant Growth Regulator	All of the turf treatments can reduce mowing and mowing costs; however, the Plant Growth Regulator (PGR) Program reduces one to two mowing cycles per year. The growth regulator program may be utilized to control the growth of cool season grasses such as fescue. A growth retardant typically interferes with cell division and thus prevents seedhead development. A plant growth regulator program can be an alternative to mechanical mowing, especially to reduce early season mowing cycles. Proper seasonal timing of this application is critical for success.
Warm Season Release	The Warm Season Release (WSR) Program controls undesirable grass and weed species while releasing or maintaining warm season turfgrasses such as bahiagrass, bermudagrass and centipedegrass. Pre-emergence and post-emergence herbicide treatments may be utilized in late winter or early spring to prevent growth of weeds and reduce early season sight distance problems and mowing cycles.
Seedhead control[1]	A Seedhead Control Program for warm season turfgrasses may also be utilized. Like the PGR program, this seedhead control program may reduce one to two mowing cycles per year in turfgrass areas that are being managed as warm season species, especially for Pensacola Bahiagrass. Such a control program has been shown to be an acceptable alternative to mechanical mowing, especially to reduce mowing cycles during the early "green-up" stage of the warm season turfgrass-growing season. Proper seasonal timing of this application is critical for success, however this type of seedhead

[1] The PGR program includes seedhead control.

	control may be applied at various warm season turfgrass developmental stages.
Broadleaf weed control	The Broadleaf Weed Control Program consists of controlling weed species along the roadsides while they are small and actively growing. Broadleaf weeds can present a major sight distance problem if not addressed properly. The presence of broadleaf weeds in roadside turfgrass can also be aesthetically undesirable, and may also prevent the desired turfgrass from becoming readily established. The Department may utilize pre-emergence or post-emergence herbicides which effectively control broadleaf weeds.
Annual grass control	The Annual Grass Control Program may utilize herbicide treatments during the summer to control annual and perennial grasses such as crabgrass, dallisgrass, broomsedge, goosegrass, and others. Annual grass control is crucial in any vegetation management program because undesirable annual and perennial grasses compete for plant nutrients during the summer months, thinning stands of desirable turf. In many cases, especially in warm season grass areas, control of undesirable annual grasses may negate or delay the need for mechanical mowing because the desirable turfgrass may not be of sufficient height to warrant the cost of a mowing cycle.

Woody vegetation management consists of five approaches, including (1) foliar brush control, (2) dormant stem treatment, (3) Kudzu control, (4) fence treatment, and (5) stump treatment (NCDOT Roadside Environmental Unit, n.d.). Table 4 shows the descriptions of each of the turf management methodologies from the NCDOT Roadside Environmental Unit website (n.d.).

Table 4 *Descriptions of methods used for woody vegetation management, verbatim from the NCDOT Roadside Environmental Unit website (NCDOT Roadside Environmental Unit, n.d.).*

Methodology	Description
Foliar brush control	Mechanical mowing remains the most frequently used method to control woody brush on rights-of-way. Mowing with a sequential Foliar Brush Control application has proven the most efficient and cost effective approach for controlling brush. The preferred process recommends mowing smaller brush late in the growing season or in winter followed by an herbicide treatment the following year after the plants re-sprouts and begins to "sucker" at the cut location. This process will control the root system and generally reduce the mowing requirements for several years. This sequence should be closely followed to avoid the need to cut or treat large brush.
Dormant stem treatment	Over the past several years, the Department has utilized Dormant Stem Treatments during the winter months. This has allowed the Department to expand the window of opportunity to control brush, without causing "brown out" to the treated vegetation. This type of brush treatment has also allowed better utilization of available personnel and equipment during normally less productive winter months.
Kudzu control	Probably the most aggressive vegetative pest in the roadside environment is kudzu. This invasive vine not only affects the highway system, but also adjacent properties and landowners. The Kudzu Control Program may consist of a cooperative eradication agreement between the Department and the adjacent landowner(s), in

	which each party agrees to control the undesirable vegetation on their respective property. The Department also targets suppression of kudzu growth in and around highway signs, bridges, guardrails, and other essential structures.
Fence treatment	The Department maintains thousands of miles of controlled-access highway routes which are bordered by fences. A Fence Treatment Program targets control of undesirable vegetation growing along these fence lines. In most cases, this is woody vegetation, such as various types of vine growth and/or small tree saplings. A fence treatment herbicide program is often used in conjunction with manual vegetation removal by inmate labor.
Stump treatment	A lesser-utilized, but promising woody vegetation control method is referred to as a Stump Treatment Program. This method is utilized where hardwood brush/trees are mechanically cut back, normally to ground level, and a systemic herbicide solution is applied directly to the cut surface. The objective of this treatment is to prevent the cut surface from regenerating new hardwood sprouts.

NCDOT Mowing Contract Administration

Prior to 2015, in most NCDOT divisions, Roadside Maintenance was responsible for managing contract mowing, while Roadside Environmental was responsible for all chemical treatments including applying PGRs. However, as a part of House Bill 97, Session Law 2015-241, section 29.9A, it was mandated that the DOT would transfer responsibility from Roadside Maintenance to Roadside Environmental:

> *The Department shall transfer from the highway maintenance units to the Roadside Environmental Unit all management functions and funding related to litter programs and roadside vegetation management* (p. 353).

In North Carolina, almost all Divisions have made the administrative transition for contract mowing responsibility from Roadside Maintenance to the Roadside Environmental staff for litter and vegetation management. Regarding mowing contracts within the NCDOT, there is a template that is used for all contracts state-wide, which are tailored to individual divisions. Appendix D includes the standard mowing contract template for division contractors.

Specifically, the following information is specified for each contract and is provided by the respective divisions: the mileage, cycles, equipment, liquidated damages, etc. Special provisions may also be included in contracts; for example, particular contracts may have provisions inserted regarding liquidated damages, completion times, and/or GPS. The scope of contracts varies, with some applicable county-wide, others division-wide, and there are even some contracts that are written for a particular route or corridor, most common on interstate or freeway facilities. (i.e. “corridor contracts”). The contract quantities are measured as shoulder miles (i.e. two shoulders per mile of two lane road: four shoulders per mile of divided highway), with contractors generally compensated at $45-50 for every primary shoulder mile, and $30-35 for every secondary shoulder mile. Contractors are typically compensated at around $110 for each interstate shoulder mile. While contracts for long-arm mowing are typically included in the contracts, they can be separate, and may not be on the same annual contract with two renewals possible if criteria are met. Long arm mowing is also compensated per shoulder mile.

Mandatory pre-bid conferences are held once every year, usually at two locations in North Carolina. The locations are often regional and determined based upon the locations of the counties that will be up for bid. In 2016, pre-bid conferences were held in Raleigh and Statesville. Bids are submitted and bid opening is held at the Transportation Building in Raleigh. The original bid opening was Nov. 22nd, 2016, and 8 of the contracts were re-bid on Jan. 19th, 2016.

Typically, 2-3 contractors bid on each contract. The following five criteria are used to assess bids for contracts, although the lowest cost is the most influential determining factor:

1. Related work experience
2. References
3. Financial stability
4. Equipment
5. Price

The contracts are for one-year terms, which can then be renewed twice by the same contractor, for a maximum of three years. The contract renewal is optional for both parties and can be refused for any reason. If the renewal option is not chosen, then the contract will be rebid.

At any given time, there are approximately 80 contracts being administered across the 14 Divisions. Annually, 20-30 contracts are put out for bid. In 2016, an estimated 31 contracts were up for bid, and bids were required to be posted on the Interactive Purchasing System by Nov. 15, 2016. The bid openings for 2017 contracts took place on Dec. 1, 2016, in Raleigh. Contractors are responsible for their own traffic control if a lane closure is needed. Additional mowing by the acre is completed as directed.

If the bidding process results in one contractor getting more work than they can handle, at their request NCDOT may contact the second-lowest bidder to transfer one or more of their contracts. A difference in expectations of the division and/or local citizens regarding vegetation management practices sometimes arises, particularly if residents are accustomed to a certain approach to vegetation management. NCDOT inspectors monitor the contractor to obtain the expected results for roadside mowing and that all aspects of the contract are being met.

Benchmarking with Peer States

Roadside vegetation management is a function carried out by Departments of Transportation in every state in the US. As such, the experience and knowledge of other states can serve as an invaluable resource for NCDOT in future decision-making. With that in mind, this section will outline the results of a brief but comprehensive benchmarking of NCDOT's vegetation management practices with those of select peer states. After a brief description below of how the states were selected and interviewed, we present the results, especially a brief primer on identified best practices that can be adopted by NCDOT in the future.

First, we begin with how the states were selected. For that purpose, the research team consulted with Roadside Environmental Unit staff at NCDOT and the following states were suggested for benchmarking comparison: Alabama, Kentucky and Texas. The common rationale for the selection of these states above is that they are well known for their vegetation management practices and are in the same general southern region of the country. In addition, names and contact information for appropriate officials in each of the states were made available to the research team for conducting the survey. Based on the above, a questionnaire was developed (Appendix C) that was approved by NC DOT before administration. Next, these officials above were contacted and detailed interviews conducted with them over the telephone as well as over email. The data collected was then compiled and forms the basis of our conclusions below.

To begin with, the following pertinent observations can be made with regards to how North Carolina compares with the other peer states in terms of the scope and size of vegetation management. As can be seen in Table 5, North Carolina showed the second greatest total area managed as well as the second greatest total area mowed. This number was second only to Texas, and greater than both Alabama and Kentucky. As the number of employees was interpreted differently between each of the four states, no conclusions could be made as to how the number of NCDOT employees compares. Texas had the highest annual budget for roadside vegetation management, at $64 million; following this, North Carolina had the second highest annual budget at approximately $62 million. Alabama was around 17.5 million, and Kentucky had an annual budget of $17 million.

Table 5 *Size and budget of other DOTs.*

	AL	TX	KY	NC
Total system miles (centerline)	**11,000**	**79,000**	**27,500**	**80,000**
Total area managed	29,273 lane miles	1.1 million acres	200,000 acres/ 27,500 miles	300,000-350,000 acres
Total area mowed	115,400 acres	800,000 acres	n/a	679,593 shoulder miles
No. of employees	4 [2]who focus on vegetation management	12,000 total in TXDOT & 1,300 applicators	2,000 maintenance crews & 660 specialty roadside applicators	279 vegetation management staff
Annual budget for Roadside Vegetation Management	$12.9 million - mowing & $4.5 million - herbicides	$50 million - mowing & $14 million - herbicides	$17 million	$62 million average annual expenditure

Organizational structure benchmarking with the peer states reveals several pertinent observations. NCDOT has fewer mowing contracts compared to TXDOT (see Table 6). While Alabama has 5 regions, North Carolina has 14. In terms of the number of counties, Texas has the greatest number (254), followed by Kentucky (120), and then North Carolina (100). Alabama showed the least number of counties (67). While Texas administers mowing contracts by county, North Carolina often lumps together several counties into a single contract, with an average of 5-6 mowing contracts per division.

Table 6 *Organizational structure of other DOTs.*

	AL	TX	KY	NC
Organizational Structure	• 5 regions • 2 areas per region • 3-6 districts per area • 41 total district offices • 67 total counties	• 25 districts • 10 counties per district • 254 total mowing contracts • 254 total counties	• 5 roadside environmental administrators • 12 highway district offices • 120 total counties	• 14 divisions • ~7 counties per division • 80 mowing contracts • 100 total counties

[2] The ALDOT number is low due to their interpretation of the question. The ALDOT representative provided the following response: "Within ALDOT we have 4 employees that are dedicated to vegetation management issues: Myself, my 2 staff members and 1 Regional Agronomist. The roadside mowing is accomplished either by contract or by District employees. All herbicide treatments are accomplished by District employees. However, those individuals are not dedicated to vegetation management; vegetation management is a part of their duties which include all roadside maintenance activities."

Previously, mowing contracts were administered by the Division Roadside Maintenance staff within the NCDOT, and applying PGRs was completed by the Roadside Environmental Division staff. As previously mentioned, in 2015, House Bill 97 mandated that all vegetation management activities would be carried out and contracted out by Roadside Environmental. While mowing will still be contracted out and application of PGRs will still be handled internally, Roadside Environmental is now responsible for ensuring the completion of both types of vegetation management activities.

Differing from NC, at KYDOT, vegetation management falls under the Division of Maintenance in the Central Office, and the Roadside Manager reports to the Director of Maintenance. The representative from the KYDOT explained that "most mechanical mowing is done by contract forces supplemented by state forces. Most spraying is done by state forces supplemented by contract forces." The other two peer states, ALDOT and TXDOT, did not specify whether vegetation management was the responsibility of Roadside Maintenance or Roadside Environmental. Instead, they both specified that vegetation management was carried out by districts. TXDOT further explained that mowing is typically contracted out.

Further delineating KYDOT's organizational structure, there are 5 Roadside Environmental state administrators who answer to the Roadside Manager. There are 12 highway district offices, and 11 of the 12 highway districts have a Roadside Environmental district administrator (REDA) who reports to the Chief District Engineer. In addition, the Highway Maintenance Superintendent (HMS) also reports to the REDA, and the Highway Equipment Operators report to the [HMS]. The KYDOT provided an organizational chart that illustrates the roles played by both roadside environmental as well as highway maintenance in the administration of vegetation management contracts (see below).

State Roadside Manager
Roadside Environment State Administrator
Roadside Environment District Administrator
Highway Maintenance Superintendent I
Highway Equipment Operator

Both the ALDOT and the TXDOT specified that contract policies to be followed by districts are set by the central office. The ALDOT central office is responsible for "developing, communicating and overseeing the policies and guidelines which outline the vegetation management program." The ALDOT central office is also responsible for overseeing "the agronomic training and education of all ALDOT employees involved in the vegetation management program."

Finally, the data collected through the interviews enable us to identify the following best practices for roadside vegetation management.

- <u>Application of Additional Cycles of Herbicides to Reduce Mowing:</u> As evidenced in ALDOT, this results in a reduction of the number of mowing cycles required and consequent savings of over $100,000 in some districts. According to the KYDOT representative, mowing too often can also impact environmental rehabilitation efforts: "maintaining vegetation at a level the public expects is a challenge given shrinking highway maintenance budgets. Our state has not embraced reduced mowing and this makes it difficult to implement pollinator habitat recovery."

- <u>Establishment of a Safe and Effective Herbicide Program:</u> A safe and effective herbicide program is essential (TXDOT, KYDOT). Applying selective herbicides during the right times of year was also mentioned as a component of a safe and effective herbicide program (TXDOT). Another interviewee mentioned that "a good herbicide program is not always that visible," meaning that bad herbicide programs would be more noticeable, due to brown-out and other negative results of managing vegetation poorly.

- <u>Establishment of an Effective Mowing and Trimming Program</u>: Representatives from the TXDOT as well as the KYDOT both mentioned the importance of an effective mowing [and trimming] program as a best practice. As expanded upon by the TXDOT representative: "mow at the right time of year (e.g. October) at the right height to encourage wildflowers, don't mow when it's wet, and establish no-mow areas to save money and to preserve wildlife and pollinator habitat.". Along these lines, the KYDOT representative emphasized the importance of prompt and effective hazardous tree removal for safety reasons.

- <u>Establishment of an Effective Herbicide Training Program:</u> Herbicide training that includes hands-on as well as classroom training is essential, according to the TXDOT representative. An effective herbicide training program would also emphasize hands-on training (e.g. how to properly mix chemicals) (TXDOT). The way that TXDOT accomplishes this is by requiring one day per year of training for all licensed herbicide applicators in order to earn re-certification credits.

NCDOT Division Vegetation Management Practices

Interviews were completed with all 14 division Roadside Environmental engineers regarding vegetation management practices (see Appendix B for a list of the interview questions). Following the qualitative analysis, several key findings arose. The first finding is that Fescue, followed by centipede grass, were most common across divisions, with Bermuda and Bahia the least common out of these main turf types. The second finding is that plant growth regulators are regularly applied on interstates and primary roads, but rarely applied on secondary roads. The third finding from the interviews is that the transfer of responsibility for administering contract mowing from roadway maintenance to roadside environmental has occurred across most divisions. The fourth finding regarding roadside management practices is that the strongest barriers to increasing the use of plant growth regulators include the following: personnel, budget, equipment, and chemical application time constraints.

Although Fescue makes up the greatest percentage of turf type on all road systems, followed by centipede grass, differences in turf were noted across road systems. On interstates and secondary systems, Bahia is more common than Bermuda; however, on primary systems, Bermuda is more common than Bahia. See Table *7* for the breakdown of turf type by percentage. Turf types are also mapped out in more detail by road system in the Appendix.

Table 7. *Average turf type percentages by road system.*

	Fescue	Bahia	Bermuda	Centipede
Interstates	67%	25%	18%	37%
Primary	69%	28%	38%	43%
Secondary	64%	38%	32%	39%

The second finding is that most divisions use plant growth regulators on interstates and primary roads, but most do not use plant growth regulators on secondary roads (see Table 8). Along with this finding, it was found that although the number of mowing cycles across all road types was consistently between 4 and 5, there were slight differences. Secondary systems averaged the highest number of mowing cycles, followed by interstates, with primary roads averaging the lowest number of mowing cycles (see Table *8*). The most common time frame to apply plant growth regulators is in March and April (n=6), followed by June (n=3), May and July (n=2). While the second finding relates to trends in mowing and applying PGRs across road types, as well as appropriate times of the year to apply PGRs, division representatives' perceptions of the effectiveness of PGRs were also delineated. Most division staff believed the use of plant growth regulators reduces the number of mowing cycles needed (n=9). Of the six who specified the number of mowing cycles that they believed an additional application of plant growth regulators would reduce, four said by one cycle and two said by two cycles.

Table 8. *PGR use and average mowing cycles by road system. Information from interviews.*

Road System	Percent of Divisions that apply PGRs	Percent of Divisions that do not apply PGRs	Average number of Mowing Cycles
Interstate	75%	25%	4.4
Primary	58%	42%	4
Secondary	23%	77%	4.6

The responsibility for mowing contracts was most commonly reported to fall under Roadside Environmental (n=10), with two divisions reporting that the responsibility is currently in transition (n=2).

The remaining two responses to the question were unique and could not be grouped together. The division 10 representative is the only one that differentiated the answer by type of road: “I administer them on Primary and Secondary routes in 4 out of the 5 counties in our division. The Maintenance unit in the 5th county mows their own, and the Interstate Maintenance Unit maintains the interstates.” The representative from division 13 mentioned that Roadside Maintenance is still responsible for mowing contracts, and that there is better coordination between applying PGRs and mowing than there had been in the past.

The fourth main finding from interviews with division staff is that barriers to increasing the use of plant growth regulators include the following: personnel (n=10), budget (n=8), equipment (n=6), timing (n=6), and other (n=4). Seven divisions reported that they would increase PGR cycles if these barriers were overcome, six indicated that they would not, and five said that they would expand the area treated. When asked about the number of PGR cycles that divisions would increase if barriers were overcome, six said that they would increase the use of PGRs by 1 cycle, and one division indicated that PGR cycles would be increased by 1-2 cycles.

Although not specifically a finding of interviews with division staff, information was gathered regarding vegetation management practices pertaining to broadleaf control, wooded vegetation, and controlling vegetation around fixed objects. All 14 Divisions indicated that they use Broadleaf Control chemicals. Six use them once per year, and two use them 1-2 times per year. The most common timeframe to apply Broadleaf Control chemicals is during May (n-6) and/or June (n=6), followed by April (n=2) and/or July (n=2). To control vegetation around fixed objects, ten divisions reported using selective chemicals, six divisions reported using non-selective chemicals, and three reported using mechanical methods. Regarding chemical treatment used for wooded species, twelve reported using chemicals containing triclopyr as the active ingredient, followed by Krenite (n=7), and other (n=4). Additionally, two other substances used for control of wooded species include Patron (n=4) and crop oil (n=3). Regarding how herbicides and mechanical methods are used to manage wooded species, ten divisions reported completing a trim followed by a chemical application.

These findings from interviews with division engineers helped to inform the study’s findings and conclusions, which will be described following the cost analysis section.

Vegetation Management Practices Cost Analysis

We constructed the database from a variety of sources. The North Carolina Department of Transportation (NC DOT) provided cost data reported by function code from fiscal year 2014 through 2016 for both mowing and PGR applications for each division as well as centerline mileage for each division. As a part of this data, the costs were broken down by road system as well (interstate/primary/secondary). Division Roadside Environmental staff provided the number of mowing and PGR application cycles per system as well as a rough percentage breakdown of turf type within their respective divisions. The number of PGR application cycles was assumed to be one, since this was the most common response in the interviews.

Based on available data, the average mowing cost per cycle per shoulder mile was calculated by system (see Figure 4). Consistent with prior conclusions from the NCDOT vegetation management cost data, interstate systems are the costliest (mean=$91.06; median=$87.17), followed by primary systems (mean=$48.59; median=$46.79), with secondary roads showing the least cost (mean=$30.33; median=$28.46).

Mowing costs in Divisions 4 ($179.25) and 13 ($171.23) were outliers compared to the median ($87.17). Information gathered from interviews showed that division 4 reported mowing two cycles annually on interstate and primary routes (5 on secondary). Division 13 reported mowing 4 cycles annually on interstate routes for Fescue and 2 cycles annually on interstate routes for warm season grasses; in comparison, division 13 reported mowing 3 cycles on both primary and secondary routes.

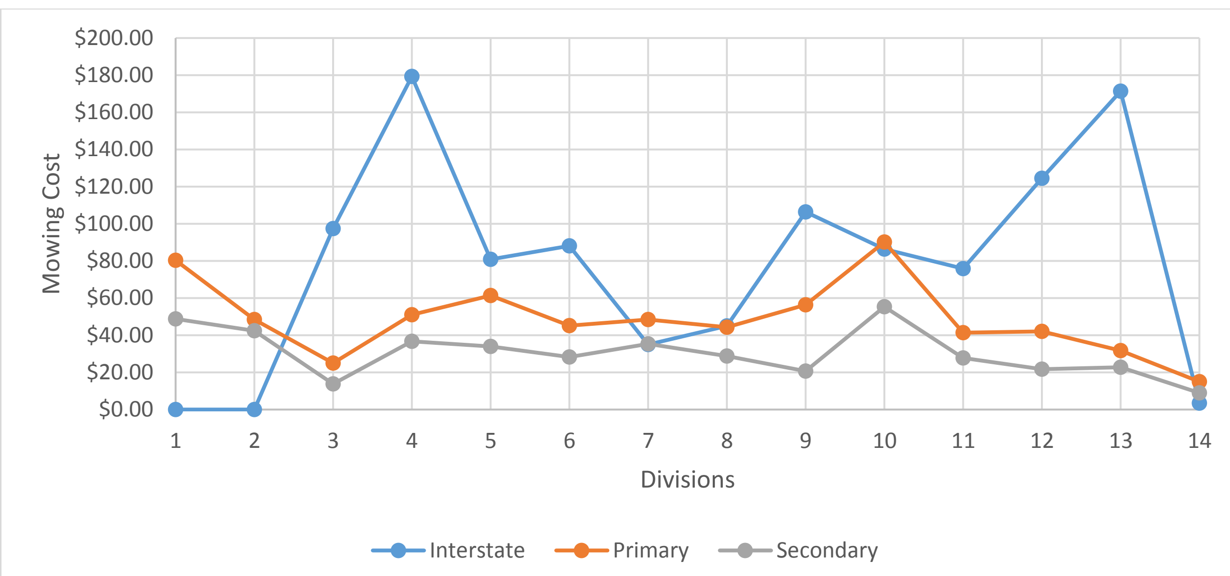

Figure 4 *Average Mowing Cost per Cycle per Shoulder Mile.*

The average cost of PGR applications per cycle per shoulder mile was calculated based on NCDOT data (see Figure 5) as well as insights from interviews. The costs associated with PGR applications on roadsides was the highest for interstates (mean=$65.70), followed by primary systems (mean=$17.04). Secondary roads were not incorporated into the graph because the costs reported are negligible, with most divisions reporting having not applied on secondary systems. The reason why interstate PGR application costs vary so much is that several divisions mentioned during interviews that although they use other herbicides, they do not use PGRs (divisions 4, 6, 8 and 14), and two divisions do not have interstates in their divisions (divisions 1 and 2). Information gathered from interviews showed that division 5 reported PGR use on interstates and primary roads, but not on secondary systems. Division 12 reported PGR use on all road types.

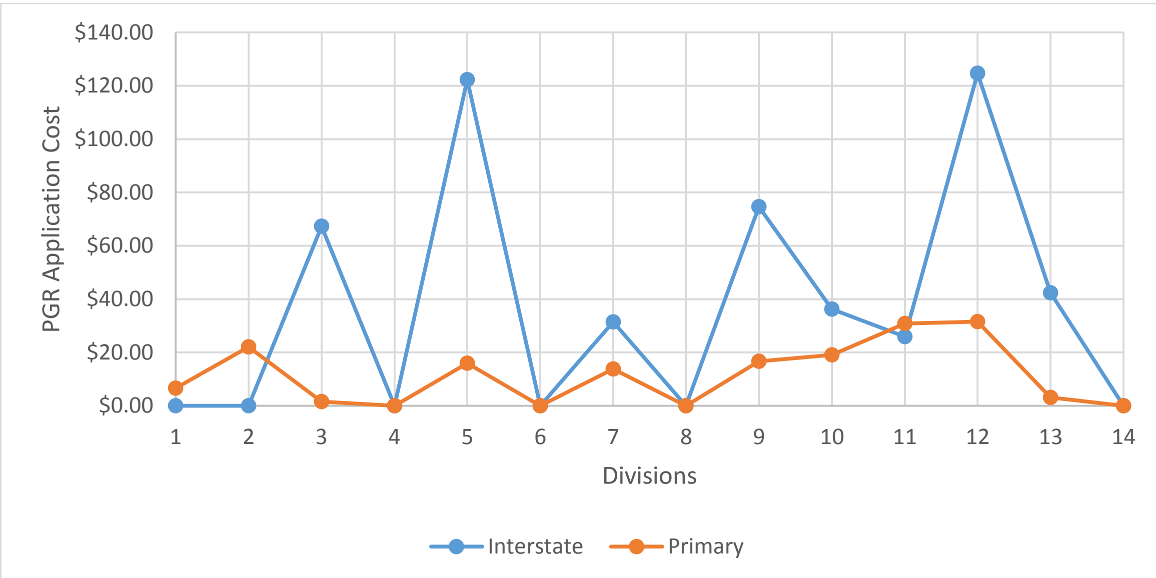

Figure 5 *Average PGR Application Cost per Cycle per Shoulder Mile.*

The ratio, or the average cost of mowing divided by the average cost of PGR applications, was calculated per cycle per shoulder mile. As displayed in Figure 6, primary systems have the greatest average ratio (mean=5.06) in comparison to interstate systems (mean=1.92). As can be seen from the line graph, an outlier for primary systems was 14.60 (Div. 3).

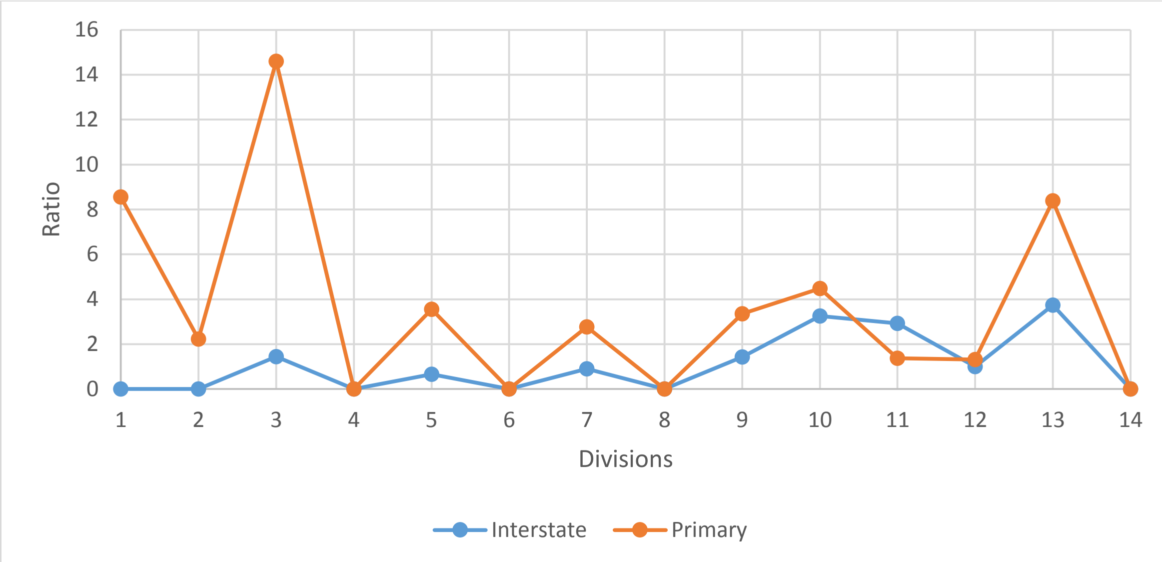

Figure 6 *Ratio of Average Cost per Cycle per Shoulder Mile (i.e. mowing divided by PGR applications).*

Table 9 displays the overall average costs for all divisions by road type, based upon available data. The first column, "mowing," refers to the overall average cost of mowing per shoulder mile. The second column, "PGR applications," lists the overall average cost of PGR applications per shoulder mile. The third column, "ratio of mow/PGR application cost," lists the ratio (i.e. mowing cost divided by PGR cost) per shoulder mile. This data can be viewed in further detail in Appendices E (interstate data), F (data for primary roads) and G (secondary data).

Table 9 *Summary of overall average costs for all divisions by road system, per cycle per shoulder mile.*

	Mowing	PGR Applications	Ratio of Mow/ PGR Application Cost
Interstate	$91.06	$65.70	1.39
Primary	$48.59	$17.04	2.85
Secondary[3]	$30.33	N/A	N/A

Table 10 displays the estimated savings for each division that might be realized by replacing one mowing cycle with one PGR application cycle. These savings are separated by road system type – interstate, primary, and secondary, as well as division totals. The total savings across all road types that are possible by reducing mowing cycles by one and increasing PGR application cycles by one was estimated to be $2,464,216 or approximately $2.5 million per year.

Overall average savings were greatest for secondary roads (mean=$98,946.57; total=$1,385,251.94), largely because divisions reported minimal PGR applications on secondary roads (see Table 9). The second highest savings were on primary roads, with an average savings

[3] Note: Although mowing cost information was retrieved for secondary systems, PGR cost data for this road type was not reliable.

of $64,968.84 by replacing one mowing cycle with one PGR application cycle (total=$909,563.82). Interstates showed the lowest potential savings, likely because divisions reported applying PGRs most extensively on interstate systems (mean=$14,116.67; total=$169,400.00).

While most of the divisions showed that replacing one mowing cycle with one PGR application cycle would result in some cost savings, there are a few exceptions to this. According to data gathered from purchase order data as well as NCDOT financial data, these divisions reported relatively high PGR application costs as well as lower than average mowing costs. Because of this, the data shows that replacing one mowing cycle with one PGR application cycle would actually result in higher costs for interstates in divisions 5, 7, 8, 12 and 14, secondary systems in division 3, as well as all road types in division 14.

Table 10 *Predicted savings accrued by replacing one mowing cycle with one PGR application cycle.*

Div.	Interstate	Primary	Secondary	Total
1	N/A	$197,295	$210,852	$408,147
2	N/A	$66,032	$174,132	$240,164
3	$10,312	$56,674	($25,469)	$41,517
4	$69,491	$97,288	$176,884	$343,663
5	($19,614)	$77,594	$148,959	$206,940
6	$6,924	$68,565	$91,754	$167,243
7	($2,946)	$41,056	$140,880	$178,990
8	($6,452)	$64,694	$124,306	$182,548
9	$10,635	$57,014	$26,080	$93,729
10	$43,675	$93,166	$189,473	$326,314
11	$9,991	$20,333	$97,037	$127,362
12	($112)	$17,924	$43,545	$61,357
13	$58,604	$55,708	$46,714	$161,026
14	($11,109)	($3,780)	($59,895)	($74,784)
Sum	$169,400	$909,564	$1,385,252	$2,464,216
Avg	$14,117	$64,969	$98,947	$176,015

Table *11* details the total shoulder mileage for mowing categorized by road system and is derived from mowing purchase orders between the NCDOT and contractors. These are overall figures that come from multiple cycles' worth of mowing. A summary of the miles by road type is also included. As can be seen in the table, secondary roads have the greatest number of shoulder mileage, with 518,873 shoulder miles reported. Following secondary roads, primary roads have the greatest share of shoulder mileage, at 139,260 shoulder miles. Interstates show the lowest shoulder mileage, at 21,460 shoulder miles. This helps to illustrate the great potential for applying PGRs on secondary roads, which is not currently being done on a systematic basis. This could reduce the cost of mowing, particularly along secondary roads.

Table 11 *Total shoulder mileage for mowing by road type.*

Div.	Interstate	Primary	Secondary
1	N/A	13,017	33,217
2	N/A	9,844	27,448
3	1,032	13,561	35,194
4	1,224	13,095	44,728
5	2,360	9,814	42,688
6	1,416	13,545	47,062
7	4,331	8,917	43,077
8	1,555	11,871	52,053
9	1,008	5,568	28,620
10	3,656	6,592	22,190
11	1,000	8,205	41,078
12	1,296	7,712	41,482
13	1,868	10,277	31,826
14	714	7,242	28,210
Sum	21,460	139,260	518,873

Table 12 displays the number of shoulder miles per cycle by road type, which was used for both mowing and PGR application calculations.

Table 12 *Per cycle shoulder mileage for mowing and applying PGRs.*

Division	Interstate	Primary	Secondary
1	N/A	4,004	10,244
2	N/A	2,432	6,850
3	344	2,804	7,556
4	624	2,792	7,126
5	472	1,908	9,034
6	404	2,460	8,322
7	1,024	1,686	7,754
8	312	2,338	10,744
9	336	1,460	7,346
10	536	1,404	5,080
11	200	1,796	9,390
12	324	1,788	9,648
13	504	2,410	8,232
14	272	1,896	9,110
Sum	5,352	31,178	116,436

Table 13 summarizes the brush and tree costs by year and category. Annual total and average costs are also included, along with the vegetation management total budget for the year and the percentage of the total budget that are brush and tree costs. The Herbicides column relates to brush and tree application costs. The Manual column relates to manual labor costs, while the Mechanical column relates to costs associated with machinery. The average percentage of the total vegetation management budget made up by brush and tree costs (including herbicides, manual and mechanical) from 2014-2016 is approximately 29%, with an average of $25,841,000 of the $90,386,486 vegetation management budget attributed to brush and tree management.

Table 13 *Brush and tree total costs from 2014 to 2016.*

FY	Herbicides	Manual	Mechanical	Total	Veg Mgmt Total Budget	Percentage of Total Budget
2014	$1,122,874	$8,180,364	$16,237,757	$25,540,995	$95,371,806	27%
2015	$762,888	$7,036,459	$15,747,160	$23,546,507	$83,781,804	28%
2016	$1,570,275	$6,001,182	$20,864,043	$28,435,499	$92,005,849	31%
Avg	$1,152,012	$7,072,668	$17,616,320	$25,841,000	$90,386,486	29%

Table 14 summarizes the brush and tree division total costs by year, category, and road system. For herbicides applied for brush and tree management, secondary roads exhibited the highest total costs ($614,948), followed by primary roadways ($325,707), with interstates showing the lowest herbicide costs ($238,229). For mechanical brush and tree costs, a similar finding was obtained: secondary roads showed the highest total cost ($12,741,292), followed by primary ($3,665,123), with interstates last ($487,465). Also consistent with these results, manual brush and tree costs followed a similar pattern, with secondary roads exhibiting the highest total cost ($4,404,847), followed by primary roads ($1,972,637), and then interstates ($291,736). The high costs attributed to secondary roads can be explained by the higher number of shoulder miles in secondary systems; likewise, the relatively low costs attributed to interstates can be attributed to the comparatively low number of shoulder miles on interstates. As can be seen in Table 6, mechanical brush and tree costs are highest, followed by manual, with herbicides last.

Table 14 *Brush and tree total costs by road type (interstates, primary, and secondary) and type of charge (herbicides, manual, and mechanical).*

FY	Herb. Inter.	Manual Inter.	Mech. Inter.	Herb. Primary	Manual Primary	Mech. Primary	Herb. Secondary	Manual Secondary	Mech. Secondary
2014	$192,757	$422,679	$666,136	$348,002	$2,495,563	$4,263,249	$582,115	$5,262,122	$11,308,373
2015	$158,809	$211,857	$446,315	$268,217	$2,316,464	$3,303,637	$335,862	$4,508,138	$11,991,719
2016	$336,929	$232,352	$338,458	$357,039	$1,105,885	$3,428,482	$876,306	$3,444,282	$14,923,784
Avg	$238,229	$291,736	$487,465	$325,707	$1,972,637	$3,665,123	$614,948	$4,404,847	$12,741,292

Table 15 summarizes the brush and tree division average costs per mile by year, category, and road system. Annual average per mile costs are also included. As can be seen in the table, mechanical costs are the highest, followed by manual, with brush and tree herbicide costs the lowest.

Table 15 *Brush and tree averages per mile by system.*

FY	Herb. Inter.	Manual Inter.	Mechanical Inter.	Herb. Primary	Manual Primary	Mechanical Primary	Herb. Secondary	Manual Secondary	Mechanical Secondary
2014	$48	$91	$180	$13	$85	$147	$7	$47	$102
2015	$41	$44	$70	$10	$79	$113	$4	$40	$111
2016	$66	$44	$55	$13	$37	$115	$10	$29	$140
Avg	$53	$61	$93	$11	$67	$125	$6	$39	$117

Inconsistencies in the Data

Upon examination of the data, inconsistencies were noted not only between NCDOT financial data and FY 2016 purchase order data collected for contract mowing, but also across fiscal years within the data (Fiscal years 2014, 2015 and 2016). We are adding this note for informational purposes primarily. However, this did make some of the analysis challenging. Figures 7 through 12 depict discrepancies in the data provided by the NCDOT.

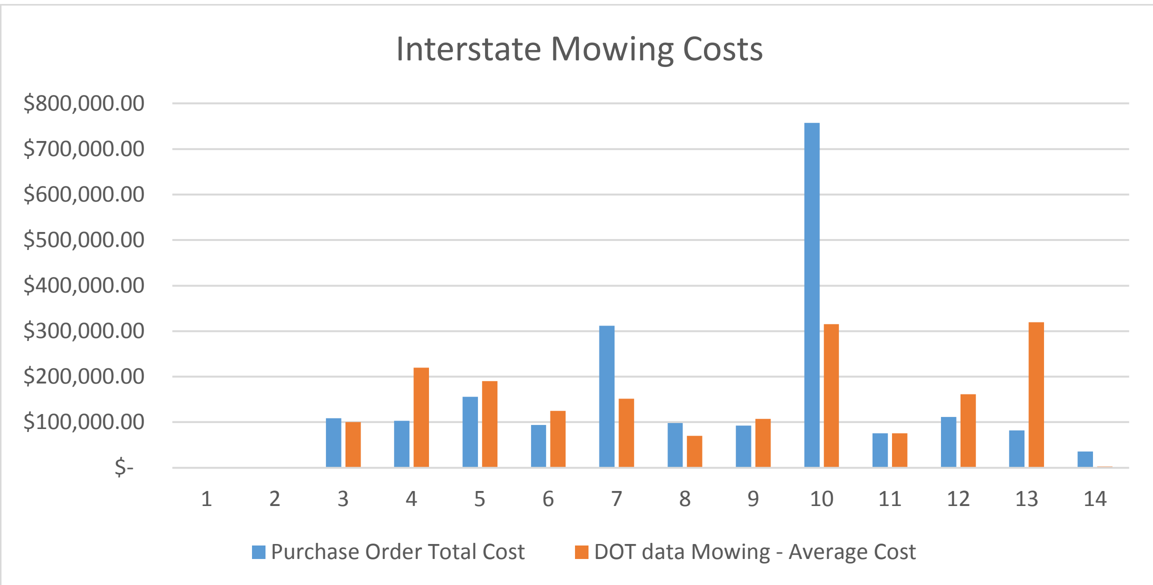

Figure 7 *Interstate mowing costs comparing purchase order data to NCDOT's financial data.*

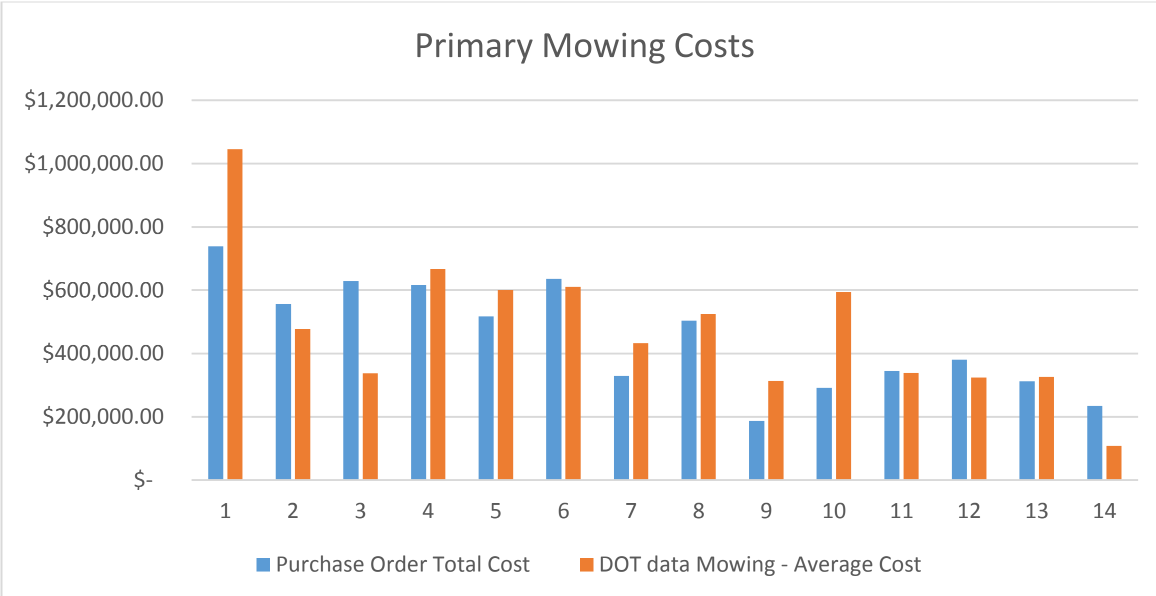

Figure 8 *Primary mowing costs comparing purchase order data to NCDOT's financial data.*

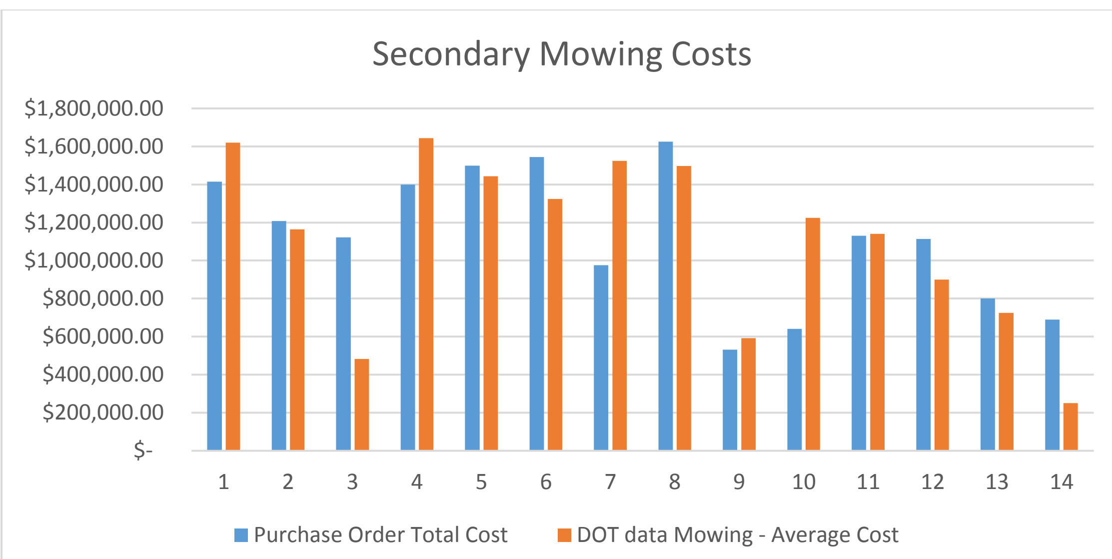

Figure 9 *Secondary mowing costs comparing purchase order data to NCDOT's financial data.*

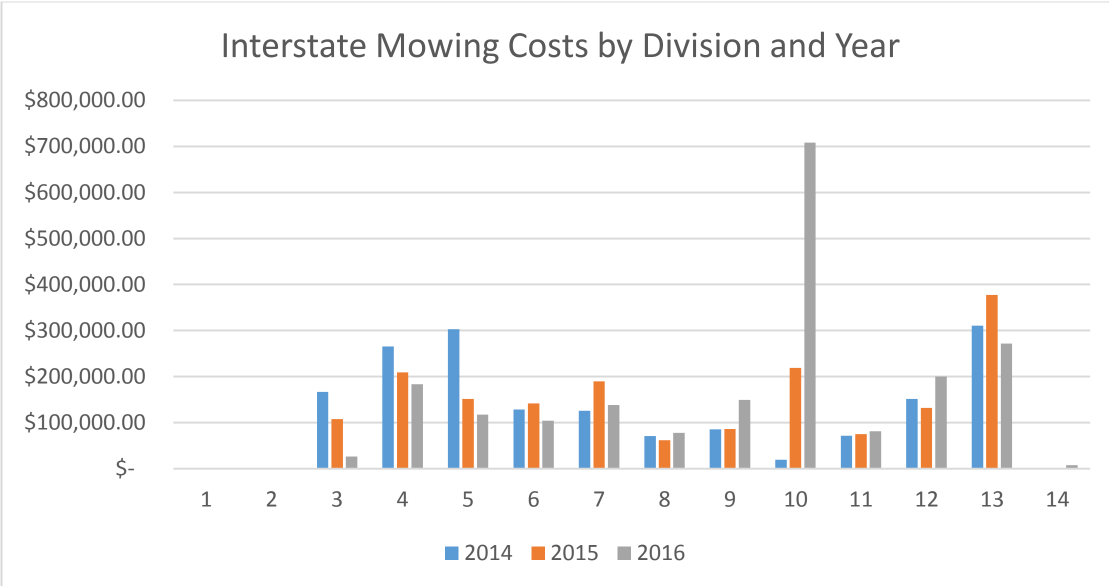

Figure 10 *Interstate mowing costs across fiscal years 2014, 2015 and 2016 as reflected in NCDOT financial records.*

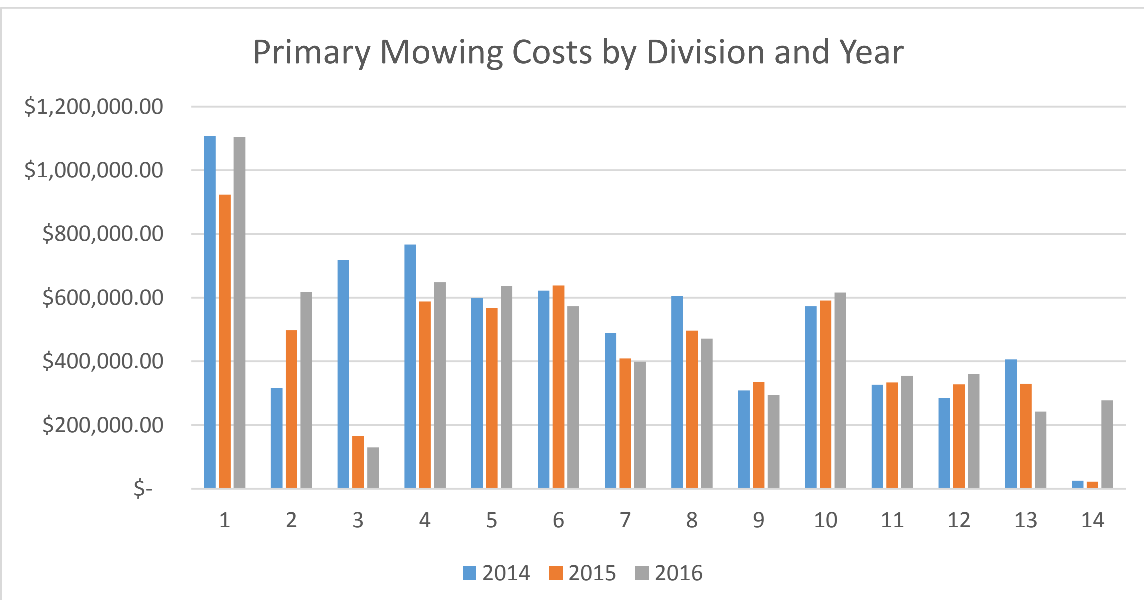

Figure 11 *Primary mowing costs across fiscal years 2014, 2015 and 2016 as reflected in NCDOT financial records.*

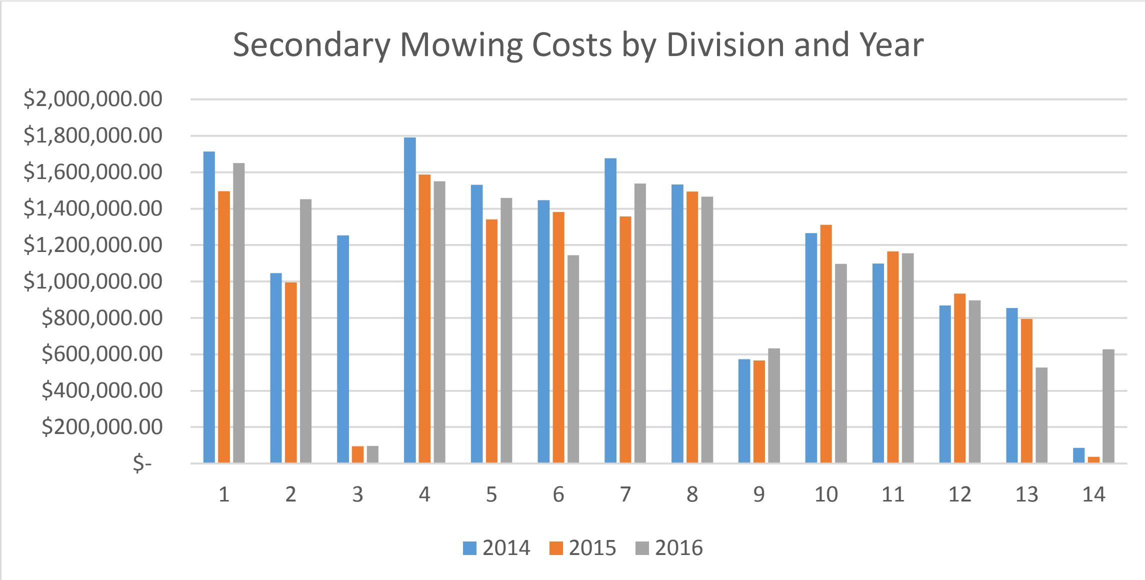

Figure 12 *Secondary mowing costs across fiscal years 2014, 2015 and 2016 as reflected in NCDOT financial records.*

Research Findings

Generally, it appears that NCDOT operates an efficient and cost effective roadside vegetation management system and utilizes many best practices identified in this study.

There were seven main findings of this research. Two of the findings came from the peer state analysis: (1) NCDOT's annual budget for roadside vegetation management is comparable to Texas, with Alabama and Kentucky reporting less extensive road networks and corresponding lower budgets in comparison to North Carolina, and (2) the literature review and peer state interviews lent support for including eco-regional approaches into integrated vegetation management plans and implementing regular, mandatory training for vegetation management professionals.

The remaining four findings came from interviews, data collection, cost analysis, literature review, and document review: (3) replacing one mowing cycle with an additional PGR application cycle on all systems may result in cost savings of $2.5 million annually; (4) coordination of PGR applications and mowing is critical for maximizing the benefits of PGRs, which was largely addressed following the passage of House Bill 97; (5) while secondary roads are mowed more frequently, interstates and primary roads are more likely to be applied with PGR applications; (6) inconsistencies were found across data sources as well as fiscal years; and (7) division staff cited the following barriers to increasing the coverage and number of PGR applications: too few personnel, budgetary restrictions, not enough equipment, and having a limited time window for successful PGR applications.

The seven main findings from this study are discussed below.

1. **NCDOT's annual budget for roadside vegetation management, as well as the size of road networks, is similar to Texas, with Alabama and Kentucky reporting lower budgets and smaller road networks**. When compared with the three peer states, NC had one of the most extensive state road networks, with 80,000 miles of highways (NCDOT, 2017), second to Texas. It was also found that the NCDOT has an annual budget ($62 million) comparable to that of Texas ($64 million) for roadside environmental management. The other two peer states, AL and KY, had lower budgets but managed road systems that were less extensive.

2. **Incorporating eco-regional approaches into integrated vegetation management plans as well as regular mandatory training for vegetation management professionals are identified best practices**. Texas in particular recommended for vegetation management practices to be safety-focused and environmental friendly, with quality, hands-on, mandatory training that reflects these standards. As a part of its environmental focus, the representative from Texas recommended encouraging the growth of wildflowers. This recommendation comes mainly from a review of the literature and is consistent with the mission of the NCDOT's Roadside Environmental Unit which is to "to provide roadside elements for a statewide highway system that are safe, environmentally sound, attractive and responsive to the public's needs" (NCDOT website, n.d.). Using weed ecology as well as indirect/cultural vegetation management practices can help to prevent the over-reliance on mowing and chemicals (Bennett, n.d.; Gover et al., 2007). As a part of this, turf as well as soil should be revitalized following herbicide/mechanical approaches by using organic material, modifying the environment and amount of shade, as well as giving the vegetation a chance to recover before continuing treatment of the area (Gover et al., 2007)). Another best practice is to make sure that any tools used to manage vegetation in one area are effectively cleaned and sanitized prior to using those same tools in another area (Bennett, n.d.). This will help to prevent the spread of weeds across different geographic areas.

3. **Replacing one mowing cycle with one cycle of plant growth regulators across all systems results in cost savings**. This finding is supported by the cost analysis, which found that replacing one mowing cycle with one PGR application cycle may result in $2.5 million in cost savings annually. This finding is also supported by the division interviews with division roadside environmental staff in which 9 out of 14 interviewees

believed that applying PGRs can decrease the number of mowing cycles needed. In the benchmarking with peer states section of the report, it was also found that the Alabama DOT representative recommended adding an additional PGR application cycle. This finding is also supported by the literature review, in which it was found that herbicides are among the most cost-efficient and effective approaches to vegetation management (Cherry, 2003; Nowak et al., 2005).

4. **Coordination of applying PGRs and mowing is critical for maximizing the benefits of PGRs**. Regarding the organizational structure of the NCDOT in terms of vegetation management, it was previously found that there had been some coordination concerns in terms of PGR applications and mowing. The second finding in the current study found that this problem has since been remediated; in section 29.9A of the 2015 budget bill (House Bill 97, Session Law 2015-241), the responsibility for mowing contracts was shifted from Roadway Maintenance to Roadside Environmental in each Division. This allows the same department, Roadside Environmental, to handle mowing and herbicide contracts, as well as to optimize the timing of mowing after chemical applications. During interviews, it was indicated that this transfer of responsibility has been completed in 10 out of the 14 divisions, with two in transition; division 13 reported having no plans to complete this transition, and division 10 reported different responsible parties depending on road type, including a unit responsible for interstate contracts. In all three peer states, divisions/districts were responsible for ensuring the execution of mowing and herbicidal application contracts, whether or not the divisions themselves or contractors were the ones carrying out the activity. In all three peer states, the central office was responsible for establishing vegetation management guidelines and policies, as well as training vegetation management staff. These facets of the organizational structure within state DOTs for vegetation management were similar to NC. While it seems likely that this transfer of responsibility for vegetation management practices will result in a greater coordination between mowing and herbicidal applications, it is too soon for conclusive data on this subject.

5. **While secondary roads are mowed more frequently, interstates and primary roads are more likely to be applied with PGR applications**. This finding relates to current vegetation management practices implemented throughout North Carolina; this information was gleaned from interviews with division engineers representing all 14 roadside divisions. It was found that 75% of the divisions reported using plant growth regulators on interstates, 58% reported applying PGRs on primary roads, with only 33% reporting use of PGRs on secondary roads. In contrast, divisions reported the highest number of mowing cycles on secondary roads (mean=4.55), followed by interstates (mean=4.38), with the fewest mowing cycles reported on primary roads (mean=4). Four out of six division engineers believed the use of PGRs to decrease the number of mowing cycles by one, and two believed the use of PGRs to reduce the mowing cycles needed by

two. Six out of 11 division engineers reported applying PGRs between March and April, three reported applying them in June, and two reported using PGRs in May and July.

6. **Inconsistencies were found across data sources as well as fiscal years**. There were inconsistencies between the purchase order data and the NCDOT fiscal data. There were also discrepancies between fiscal years within the NCDOT mowing and PGR data. This suggests potentially inconsistent reporting practices across fiscal years.

7. **The following barriers to increasing the coverage and number of PGR applications were identified in interviews: too few personnel, budgetary restrictions, not enough equipment, and having a limited time window for successful PGR applications**. This information was derived through interviews with the 14 NCDOT division representatives. Specifically, it was reported that inadequate personnel (n=10), a low budget (n=8), not enough equipment (n=6), limited timing for applying PGRs (n=6), and other reasons (n=4) were mentioned as barriers to increasing PGR usage. Although cost savings are associated with increasing the number of PGR application cycles and reducing the number of mowing cycles, only half of the divisions (n=7) noted that they would increase PGR cycles if barriers were overcome; six division engineers reported that they would not increase their usage of PGRs if barriers were overcome, and five indicated that they would expand the area treated. Additionally, six division staff reported that they would increase the number of PGR application cycles by one, and one division staff indicated that he would increase the number of PGR cycles by 1-2.

Recommendations

In light of the above findings, there are five recommendations that are supported by this research:

1. **Consider one additional PGR application cycle, which may reduce one mowing cycle resulting in cost savings of approximately $2.5 million per year.** This recommendation is consistent with the first finding, which is that cost savings can be realized by replacing one mowing cycle with an additional PGR cycle. Notably most of this savings can be seen from utilizing PGRs on the secondary system where essentially none is used presently. This recommendation is also consistent with feedback from the peer state ALDOT representative, who identified supplanting one mowing cycle with an additional PGR application cycle. Prior research has also supported the efficacy and cost-effectiveness of herbicides (Cherry, 2003; Nowak et al., 2005). However, it is important to note that the findings of this research do not lend support to unlimited increases in the use of PGRs. One additional constraint is that NCDOT division staff identified a limited time frame for the effective application of PGRs (i.e. March through July).

2. **Continue to monitor the effective coordination between mowing and PGR applications, with the help of the Roadside Vegetation Management Tool to monitor costs of vegetation management practices.** This recommendation follows from the finding that House Bill 97 (2015) streamlined the responsibilities for vegetation management along NC roadsides under Roadside Environmental, making coordination between mowing and herbicidal applications more effective. In addition, discussions during interviews indicated that 12 out of 14 divisions had completed this transfer of responsibility, while two divisions still maintained Roadside Maintenance's role in vegetation management in some form. This recommendation to effectively coordinate mowing and herbicidal applications was supported by two of the peer state representatives (KYDOT, TXDOT). While this may be partially remediated due to mandated transfer of responsibility from Roadside Maintenance to Roadside Environmental (section 29.9A in House Bill 97, Session Law 2015-241), there is a need to monitor the continued coordination between mowing and herbicidal applications for maximum effectiveness following the transition. Under optimal conditions, projected cost savings should be realized; in contrast, under suboptimal weather conditions, the actual cost savings could be lower than what is projected in this report (this is supported by interviews). This is consistent with a recommendation by the representative for the TXDOT, in the benchmarking with peer states section of the report, who recommended to apply PGRs and mow and the right times of the year according to established practices.

3. **Effectively integrate eco-regional approaches into vegetation management practices**. For example, establishing non-mow areas, encouraging the use of wildflowers and native species, revitalizing turf and soil, and following other best practices are all aspects of eco-regional approaches. These are all supported in the literature on integrated vegetation management plans (Bennett, n.d.; Gover et al., 2007). Regular, mandatory hands-on vegetation management training for responsible staff consistent with an eco-regional approach to an integrated vegetation management plan that is based on the most effective practices was recommended by TXDOT.

4. **Standardize cost reporting practices for mowing and PGR applications.** This could help make NCDOT fiscal data more consistent across fiscal years. For example, one division representative mentioned during interviews that in FY 2015, they used function code 2908 ("Brush and Tree Control") a lot to report turf management (i.e. herbicide use), rather than function code 2904 ("Turf Management"). Standardizing these reporting practices can facilitate a more precise analysis in the future.

5. **Address the most common barriers to increase PGR usage as reported in the interviews with NCDOT division staff.** The most commonly mentioned barriers to increasing PGR usage, as identified in finding 6, are related to a lack of resources;

specifically, a lack of personnel, equipment, and a low budget were the barriers most often mentioned in interviews. Following these budget-related barriers is that there is a limited window of time where applying PGRs is effective (i.e. March through July). However, there is a caveat to this recommendation: during interviews, only half of the division roadside engineers said that they would increase the number of PGR cycles applied if these barriers were overcome, with five saying that they would increase the area treated. In fact, six division roadside engineers explicitly stated that they would not increase PGR usage even if obstacles were remediated.

Close-out Implementation Plan

NCDOT Research and Development

RP 2016-17 Economic Analysis of Vegetation Management Practices

Project Start Date: 8/01/2015

Project Completion Date: 7/31/2017

Project Cost: $186,127

Customers and Stakeholders

David Harris	Kevin Clemmer
Derek Smith	Neil Mastin
Don Lee	Morgan DeWit

Deliverables received:

- X Literature Search Results
- X Quarterly Progress Reports
- X Draft Final Report
- ☐ Final Report

P. I.'s Recommendations per Final Report *(see attached):*

1. **Consider one additional PGR application cycle, which may reduce one mowing cycle**
2. **Continue to monitor the effective coordination between mowing and PGR applications, with the help of the Roadside Vegetation Management Tool.**
3. **Effectively integrate eco-regional approaches into vegetation management practices.**
4. **Standardize cost reporting practices for mowing and applying PGRs.**
5. **Address the most common barriers to increase PGR usage.**

Implementable Research Products *(output): The primary implementable research product from this project are the 5 recommendations above.*

Implementation Plan *(Now what?): (For suggestions, see list on the other side)*

Training: *Training may be required for Recommendation #4 above.*

Outreach: *Outreach is necessary to* Division personnel *for implementing Recommendation #1 above. In addition, outreach will also be necessary to identify the necessary rectifications for the barriers ,mentioned in Recommendation #5.*

Revise documents *(e.g., specifications design guidelines, etc.): N/A*

Application to processes *(e.g., design):* *N/A*

Application to projects: Meetings with Division personnel *necessary to implement Recommendation #1*

Other: *N/A*

Anticipated Benefits *(outcome): Implementing Recommendation #1 can save $2.5 million/year and the same for Recommendation #5 can increase these savings. Implementing Recommendation #4 will lead to more accurate and consistent cost information for future analysis projects.*

How can Research and Development Unit participate? *Coordinate communication and outreach.*

Any other comment: *N/A*

Your Name *James B Martin* Date __7__ - ___31__ - __2017____

Suggested Examples of Research Product Implementation Action Items

Training:

Develop training documents
Develop training video
Arrange for training classes and workshops
Arrange for software demonstrations

Outreach:

Arrange for media release through PIO
Publish newsletters, research digest, etc.
Publish in the website
Present to professional organizations and other agencies
Expand distribution of the Final Report

Revise Documents:

Write or revise Specifications
Write Special Provisions
Develop new or revise written policies and procedures
Develop languages for legislation and for BOT

Application to Processes:

Establish new design procedures
Stop out-of-date processes
Recommend to external agencies and/or organizations
Develop agreements / partnerships
Form a Working Group
Establish need for additional equipment, parts, Materials, etc.

Application to Projects:

Apply results to meet permit commitments or requirements or to avert legal challenges
Trial use on specific projects (TIP no., Contact no., locations, etc.)
Seek additional funds for construction innovations
Develop cost estimates
Engage upper level management
Meetings with Division personnel

Other:

Additional in-house laboratory and/or field testing
Get input from other DOTs
Perform B/C Analysis
More research???
Distribute Surveys & Questionnaires

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Young, S.L. (2003). *Exploring alternative methods for vegetation control and maintenance along roadsides*. Hopland Research and Extension Center, University of California: Hopland, CA. Retrieved from http://www.dot.ca.gov/newtech/researchreports/2002-2006/2003/alternative_vegetation_control_final_report.pdf.

Appendices

Appendix A. List of interview participants.

	Title	Interview date	Medium
1	Div. 1 Roadside Environmental Engineer	5/18/2016	Email
2	Div. 2 Roadside Environmental Engineer	5/19/2016	Email
3	Div. 3 Roadside Environmental Engineer	5/24/2016	Email
4	Div. 4 Roadside Environmental Engineer	5/18/2016	Email
5	Div. 5 Roadside Environmental Engineers	4/29/2016	In person
6	Div. 6 Roadside Environmental Engineer	6/06/2016	Email
7	Div. 7 Roadside Environmental Engineers	10/30/2015	In person
8	Div. 8 Roadside Environmental Engineer	5/27/2016	Email
9	Div. 9 Roadside Environmental Engineers	3/23/2016	In person
10	Div. 10 Roadside Environmental Engineer	5/18/2016	Email
11	Div. 11 Roadside Environmental Engineer	9/14/2016	In person
12	Div. 12 Roadside Environmental Engineer	5/18/2016	Email
13	Div. 13 Roadside Environmental Engineer	9/16/2016	In person
14	Div. 14 Roadside Environmental Engineer	5/23/2016	Email
15	Roadside Environmental Supervisor	n/a	In person
16	Roadside Environmental Unit	10/21/2015	In person
17	Forester, Duke Energy	n/a	In person
18	ALDOT representative	11/01/2016	Email
19	KYDOT representative	11/01/2016	Email
20	TXDOT Director of Vegetation Management	11/14/2016	Email

Appendix B. Interview Questions

1. What is the predominant turf type and species on roadsides in your division? If there are multiple, what is the estimated percentage of each?
2. Do you apply Plant Growth Regulators? If so, when?
3. In your opinion, does the use of PGRs reduce the necessary number of mowing cycles? If so, how many?
4. On average, how many mowing cycles are performed every year?
5. Do you administer turf mowing contracts in your division? If not, who does?
6. Do you apply Broadleaf Control chemicals? If so, how often and when?
7. What kind of special treatments or procedures are used for control around fixed objects? (i.e. guard rails, cable barriers, signs, bridge ends, etc.)
8. What chemical treatment is utilized for wooded species control?
9. How is that treatment coordinated with mechanical wooded species control?
10. What are the barriers to increasing the number of plant growth regulator applications? If you had adequate resources, would you increase the number of plant growth regulator applications during the growing season, and if so, to how many per year?

Appendix C. Questions for Benchmarking with Peer States

1. What is the total acreage/mileage of vegetation managed in your department? How many employees are staffed? What is your annual budget?
2. Can you provide the organizational structure in your state for vegetation management? Are herbicidal treatments handled by the same department that handles mechanical vegetation control (e.g. mowing)? If you could provide us with an organizational chart of the organization responsible for vegetation management, this would be especially helpful.
3. What are the vegetation management practices followed in your state? Of particular importance to us are the following aspects of vegetation management: turf management (mowing as well as herbicidal applications), guardrail and fixed object vegetation control, as well as broadleaf management.
4. Based upon your experience, what would you consider to be 3-5 best practices for vegetation management in your state?
5. Are there any additional comments you would like to include regarding your vegetation management program? This can include emerging trends, challenges, and concerns, among others.
6. If you have any supporting documentation or background information regarding your state's vegetation management practices, that would be helpful.

Appendix D. Table of contents for the mowing template for NCDOT vegetation management contractors, followed by a sample bid sheet.

Table of Contents

STATE OF NORTH CAROLINA
NORTH CAROLINA DEPARTMENT OF TRANSPORTATION
PURCHASING DEPARTMENT
1 SOUTH WILMINGTON STREET, ROOM 412
RALEIGH, NC 27601

IMPORTANT BID ADDENDUM

November 30, 2015

FAILURE TO RETURN THIS ENTIRE BID ADDENDUM IN ACCORDANCE WITH INSTRUCTIONS SHALL SUBJECT YOUR BID TO REJECTION ON THE AFFECTED ITEMS:

Bid Number: **54-SM-04-11540991**
Addendum Number: **1**
Purchaser: **Sharon McCalop**

Service/Commodity: **Highway Mowing**
Using Agency: **Nash, Wilson**
Opening Date/Time: **December 2, 2015 at 1:00 PM**

INSTRUCTIONS: **Please adhere to the following changes on the bid referenced above:**

1. **The bid form quantities were incorrectly calculated in the RFP as advertised. Note the change in mileages below:**

		Cycles			
System	**Miles**	*Routine*	*Clean-up*	*Long-arm*	*Guardrail*
Interstate	50		2		
Primary Divided	113		2		
Primary Undivided	292	3	2		
Secondary Divided	5	3	2		
Secondary Paved	1389	3	2		
Secondary Unpaved	1	5			

2. **Replace the Contract Bid Form of the Bid Submittal Package with the following page to reflect a change in quantities:**

CONTRACT BID FORM

ITEM	SEC	DESCRIPTION	QTY	UNIT	UNIT PRICE	AMOUNT BID
1	SP	Mowing – Interstate – RT		SHM	$	$
2	SP	Mowing – Interstate – CU	400	SHM	$ 80	$ 32,000
3	SP	Mowing – Primary Divided – RT		SHM	$	$
4	SP	Mowing – Primary Divided – CU	904	SHM	$ 80	$ 72,320
5	SP	Mowing – Primary Undivided – RT	1752	SHM	$ 40	$ 70,080
6	SP	Mowing – Primary Undivided – CU	1168	SHM	$ 45	$ 52,560
7	SP	Mowing – Secondary Divided – RT	60	SHM	$ 48	$ 2880
8	SP	Mowing – Secondary Divided – CU	40	SHM	$ 50	$ 2000
9	SP	Mowing – Secondary Paved – RT	8334	SHM	$ 35	$ 291,690
10	SP	Mowing – Secondary Paved – CU	5556	SHM	$ 42	$ 233,352
11	SP	Mowing – Secondary Unpaved – RT	10	SHM	$ 36	$ 360
12	SP	Mowing – Additional		ACR	$	$
13	SP	TCD (Median Guardrail)		SHM	$	$
14	SP	Guardrail Trimming		SHM	$	$
15	SP	Longarm Operation		SHM	$	$
16	SP	Lane Closure		EA	$	$
		TOTAL BID FOR PROJECT: $				757,242

FOR NCDOT USE ONLY
Offer accepted and contract awarded this 5th day of February, 2016, as indicated on attached certification,

by [illegible] (Authorized representative of the NCDOT)

Bid Submittal Package – 3

Appendix E. Overall average costs for interstates by division

Div.	Mowing - Avg Cost/SHM	PGRs - Avg Cost/SHM	Ratio - Avg Cost/SHM	Mowing - Avg Cost/ Cycle/SHM	PGRs - Avg Cost/ Cycle/SHM	Ratio - Avg Cost/ Cycle/SHM
1	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A
3	$292.01	$68.74	4.25	$97.34	$68.74	1.42
4	$358.50	$145.93	2.46	$179.25	$145.93	1.23
5	$403.73	$182.54	2.21	$80.75	$182.54	0.44
6	$403.07	$104.29	3.86	$88.08	$104.29	0.84
7	$180.95	$40.08	4.51	$34.96	$40.08	0.87
8	$224.79	$1.57	143.30	$44.96	$1.57	28.66
9	$318.78	$135.65	2.35	$106.26	$135.65	0.78
10	$431.31	$26.53	16.26	$86.26	$26.53	3.25
11	$379.43	$25.93	14.63	$75.89	$25.93	2.93
12	$497.32	$201.09	2.47	$124.33	$201.09	0.62
13	$684.92	$81.68	8.39	$171.23	$81.68	2.10
14	$13.87	$0.00	N/A	$3.47	$0.00	N/A
Avg	**$349.06**	**$84.50**	**18.61**	**$91.06**	**$84.50**	**3.92**

Appendix F. Overall average costs for primary roads by division.

Div.	Mowing - Avg Cost/SHM	PGRs - Avg Cost/SHM	Ratio - Avg Cost/SHM	Mowing - Avg Cost/ Cycle/SHM	PGRs - Avg Cost/ Cycle/SHM	Ratio - Avg Cost/ Cycle/SHM
1	$375.85	$52.13	7.21	$80.31	$52.13	1.54
2	$193.12	$43.45	4.44	$48.46	$43.45	1.12
3	$138.42	$1.74	79.45	$24.92	$1.74	14.30
4	$232.95	$48.17	4.84	$50.99	$48.17	1.06
5	$340.87	$25.76	13.23	$61.26	$25.76	2.38
6	$250.43	$7.31	34.28	$45.13	$7.31	6.18
7	$325.97	$18.24	17.87	$48.48	$18.24	2.66
8	$219.96	$23.43	9.39	$44.18	$23.43	1.89
9	$216.83	$30.57	7.09	$56.27	$30.57	1.84
10	$445.98	$20.09	22.20	$90.07	$20.09	4.48
11	$184.99	$30.19	6.13	$41.29	$30.19	1.37
12	$183.68	$51.55	3.56	$42.10	$51.55	0.82
13	$163.71	$6.76	24.24	$31.74	$6.76	4.70
14	$58.26	$0.01	6476.16	$15.02	$0.01	1669.41
Avg	**$237.93**	**$25.67**	**479.29**	**$48.59**	**$25.67**	**122.41**

Appendix G. Overall average costs for secondary roads by division.

Div.	**Mowing - Avg Cost/SHM**	**PGRs - Avg Cost/SHM**	**Ratio - Avg Cost/SHM**	**Mowing - Avg Cost/ Cycle/SHM**	**PGRs - Avg Cost/ Cycle/SHM**	**Ratio - Avg Cost/ Cycle/SHM**
1	$243.67	$1.21	200.78	$48.76	$1.21	40.18
2	$169.67	$1.01	168.36	$42.42	$1.01	42.09
3	$63.43	$0.89	71.12	$13.69	$0.89	15.35
4	$182.89	$0.16	1133.29	$36.73	$0.16	227.61
5	$162.73	$6.30	25.81	$33.83	$6.30	5.37
6	$160.29	$0.07	2447.54	$28.15	$0.07	429.76
7	$198.26	$0.00	N/A	$35.37	$0.00	N/A
8	$141.25	$0.15	929.18	$28.77	$0.15	189.24
9	$81.83	$0.09	906.39	$20.65	$0.09	228.76
10	$246.75	$0.06	4302.59	$55.21	$0.06	962.64
11	$125.79	$0.14	890.99	$27.75	$0.14	196.55
12	$95.97	$1.43	66.91	$21.69	$1.43	15.12
13	$89.28	$0.09	1015.94	$22.79	$0.09	259.35
14	$34.14	$0.01	3809.16	$8.88	$0.01	991.22
Avg	**$142.57**	**$0.83**	**1228.31**	**$30.33**	**$0.83**	**277.17**

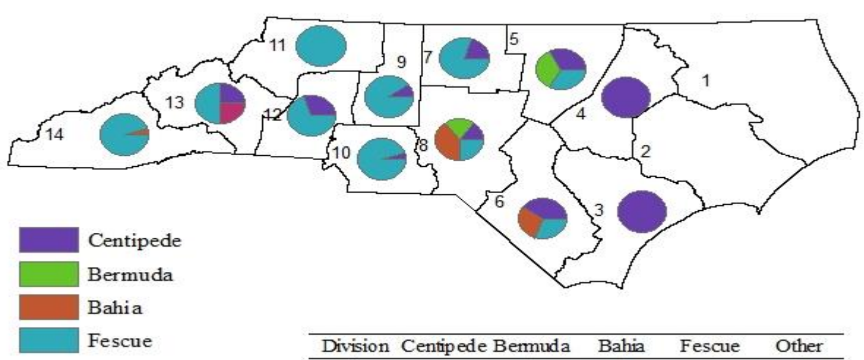
Appendix H. Analysis of interviews by question.

Summary of Information obtained from Interviews with NCDOT Division Representatives

Out of 14 NCDOT roadside environmental engineers representing the 14 divisions that were initially contacted, all 14 participated in either in-person or telephone interviews. Division numbers 1 and 2 do not have an interstate included in their divisions. A copy of the interview list is displayed in Appendix A, and interview questions are included in Appendix B.

Question 1: What is the predominant turf type and species on roadsides in your Division? If there are multiple what is the estimated percentage of each? All 14 interview participants provided answers to this question. See the tables below for percentages of the four types of turf, sorted by the type of roadway system and by division. Table 16 shows that both centipede grass and Fescue are the most common turf types found along interstates in North Carolina (10 out of 12 interview participants reported a presence of this species in their divisions). Bermuda and Bahia are the next most prevalent (both were mentioned by 3 out of 12 interviewees). "Other" was mentioned once, with division 13 reporting a presence of zoysia in the division. The mean percentage of centipede grass presence in interstate systems is 36.8%, the mean percentage of Fescue is 66.8%, for Bermuda the average percentage is 18%, and the average percentage of Bahia is 25%. This shows that Fescue is used in the largest percentage when compared to other turf types, with centipede grass making up the second largest percentage. Bahia is used in greater percentages than Bermuda.

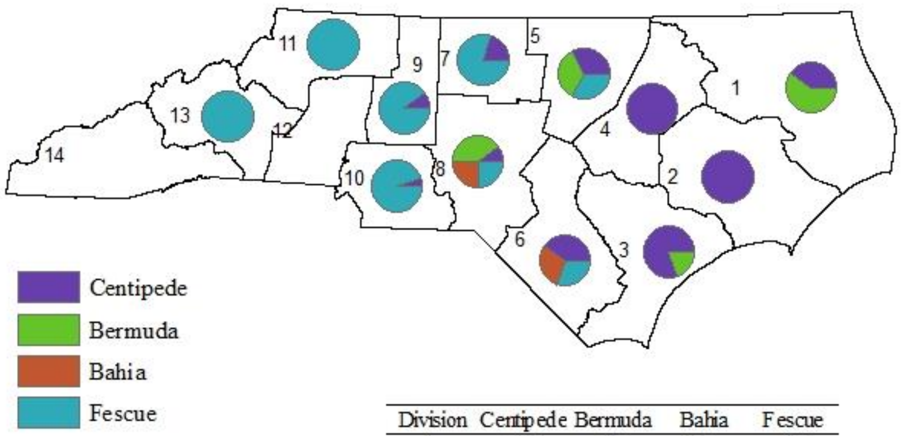
Table 16 Turf types in interstate systems separated by division number.



Division	Centipede	Bermuda	Bahia	Fescue	Other
1	n/a	n/a	n/a	n/a	n/a
2	n/a	n/a	n/a	n/a	n/a
3	100%	<1%	0%	0%	n/a
4	>90%	0%	0%	0%	n/a
5	33%	33%	0%	33%	n/a
6	40%	0%	30%	30%	n/a
7	20%	0%	0%	80%	n/a
8	15%	20%	40%	25%	n/a
9	10%	0%	0%	90%	n/a
10	<5%	0%	0%	>95%	n/a
11	0%	0%	0%	100%	n/a
12	30%	0%	0%	70%	n/a
13	25%	0%	0%	50%	25%
14	0%	0%	5%	95%	n/a

Table 17 shows that centipede grass is the most common type of turf found along primary roads in North Carolina (10 out of 12 interview participants reported a presence of this species in their divisions), Fescue is the next most prevalent (8 out of 12), followed by Bermuda (4 out of 12) and Bahia (2 out of 12). The mean percentage of centipede grass presence in primary roadway systems is 42.8%, the mean percentage of Fescue is 69.13%, for Bermuda the average percentage is 38.25%, and the average percentage of Bahia is 27.5%. This shows that Fescue is present in a larger percentage when compared to centipede grass, followed by Bermuda and then Bahia. While Bermuda is present more than Bahia for primary roads, the opposite is true of interstate systems.

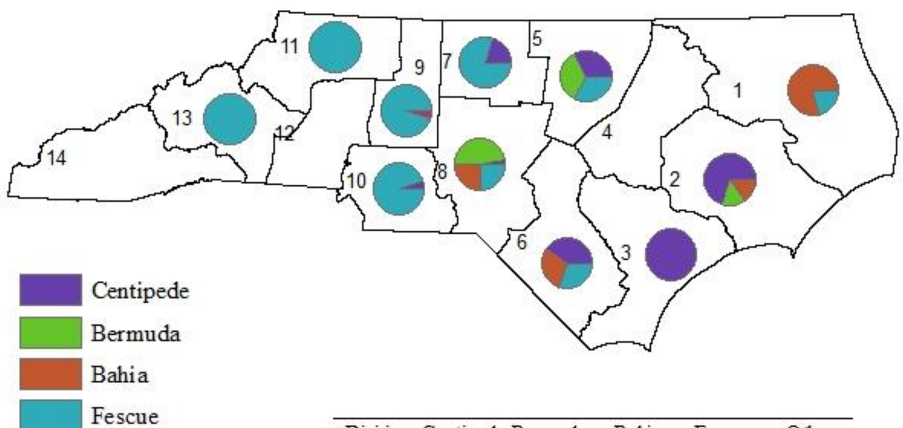
Table 17 Turf types in primary roadway systems separated by division.



Division	Centipede	Bermuda	Bahia	Fescue
1	40%	60%	0%	0%
2	100%	0%	0%	0%
3	80%	20%	0%	0%
4	>90%	0%	0%	0%
5	33%	33%	0%	33%
6	40%	0%	30%	30%
7	20%	0%	0%	80%
8	10%	40%	25%	25%
9	10%	0%	0%	90%
10	<5%	0%	0%	>95%
11	0%	0%	0%	100%
12	n/a	n/a	n/a	n/a
13	0%	0%	0%	100%
14	n/a	n/a	n/a	n/a

Table 18 shows that Fescue is the most common type of turf found along secondary roads in North Carolina (9 out of 11 interview participants reported a presence in their divisions). Centipede grass is the next most commonly mentioned turf type (7 out of 11), Bahia is the next most prevalent (4 out of 11), followed by Bermuda (3 out of 11). One interview participant listed other types of turf found in their division (division 9). The mean percentage of centipede grass presence in secondary roadway systems is 38.71%, the mean percentage of Fescue is 64.22%, for Bermuda the average percentage is 31.67%, and the average percentage of Bahia is 37.5%. This shows that the percentage makeup of turf types between interstates and secondary roadway systems are more similar when compared to primary roadway systems. While Fescue followed by centipede grass makes up the greatest percentage for all three roadway types, for interstates and secondary roads, Bahia makes up a greater percentage than Bermuda grass. In contrast, for primary roadway systems, Bermuda grass makes up a greater percentage of the turf species than Bahia.

Table 18 *Turf types in secondary roadway systems separated by division.*



Division	Centipede	Bermuda	Bahia	Fescue	Other
1	0%	0%	80%	<20%	0%
2	70%	15%	15%	0%	0%
3	100%	0%	0%	0%	0%
4	n/a	n/a	n/a	n/a	0%
5	33%	33%	0%	33%	0%
6	40%	0%	30%	30%	0%
7	20%	0%	0%	80%	0%
8	3%	47%	25%	25%	0%
9	0%	0%	0%	95%	5%
10	<5%	0%	0%	>95%	0%
11	0%	0%	0%	100%	0%
12	n/a	n/a	n/a	n/a	n/a
13	0%	0%	0%	100%	0%
14	n/a	n/a	n/a	n/a	n/a

Question 2: Do you apply Plant Growth Regulators? If so when?

Nine out of the 12 interview participants who have interstates in their divisions (#3, 5-7, 9, 11-14) said that they do use plant growth regulators along interstates, while 3 said that they do not (#4, 8, 10). This reveals that the majority of interstates in North Carolina divisions do apply plant growth regulators to control plant growth. This data is displayed in Figure 13.

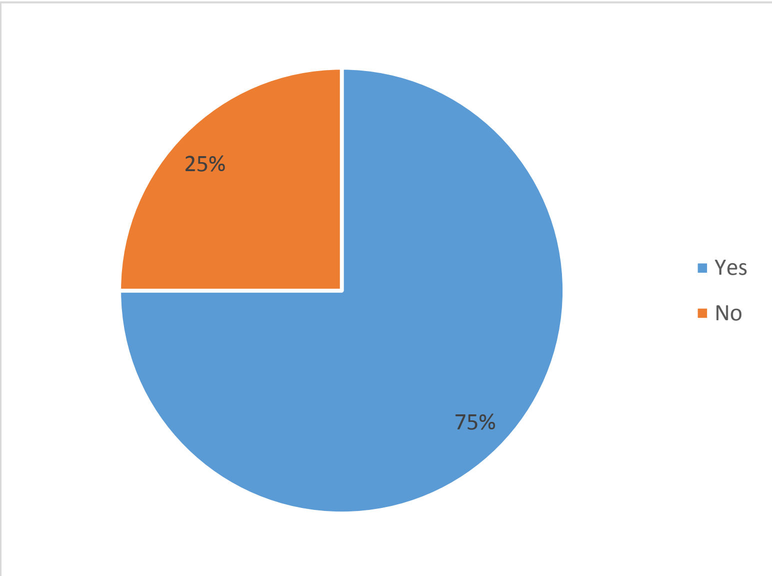


Figure 13 *The percentage of participants who use PGRs on interstates*.

Twelve out of the 14 interview participants provided information about PGRs used on primary roads (divisions 13 and 14 did not provide an answer to this question). Seven said that they do use PGRs on primary roads (divisions # 1, 2, 5, 6, 7, 9, 12) and 5 said that they do not use PGRs on primary roads (divisions # 3, 4, 8, 10, 11). This reveals that the majority of primary roads in North Carolina divisions including do apply plant growth regulators to control plant growth. This data is shown in Figure 14.

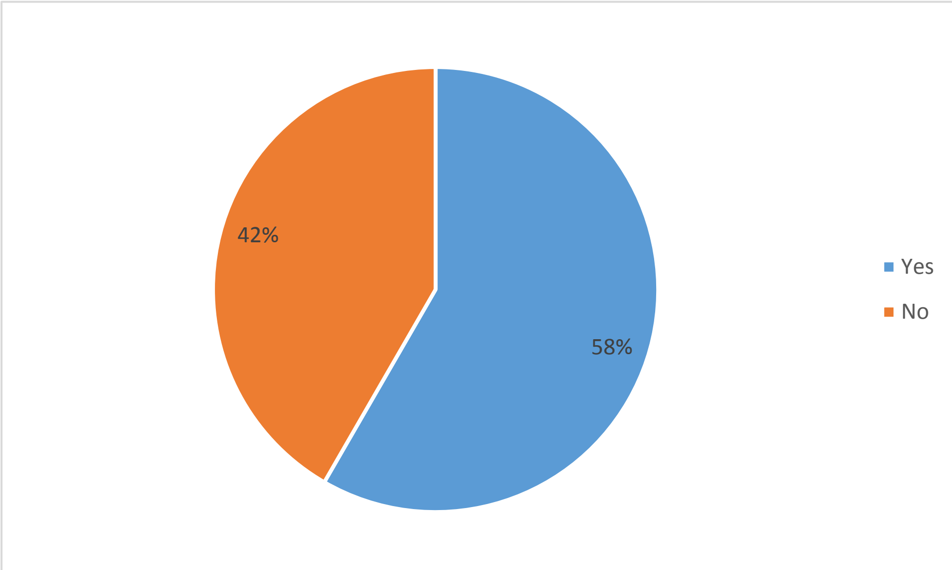


Figure 14 *The percentage of participants who use PGRs on primary roads.*

Thirteen out of 14 interview participants provided information about PGRs used on secondary roads. Ten said that they do not use PGRs on secondary roads (divisions #1, 3-11) and 3 said that they do use PGRs on secondary roads (divisions #2, 12, 14). This shows that the majority of secondary roadways in North Carolina divisions do not apply plant growth regulators to roadside vegetation. This data is displayed in Figure 15.

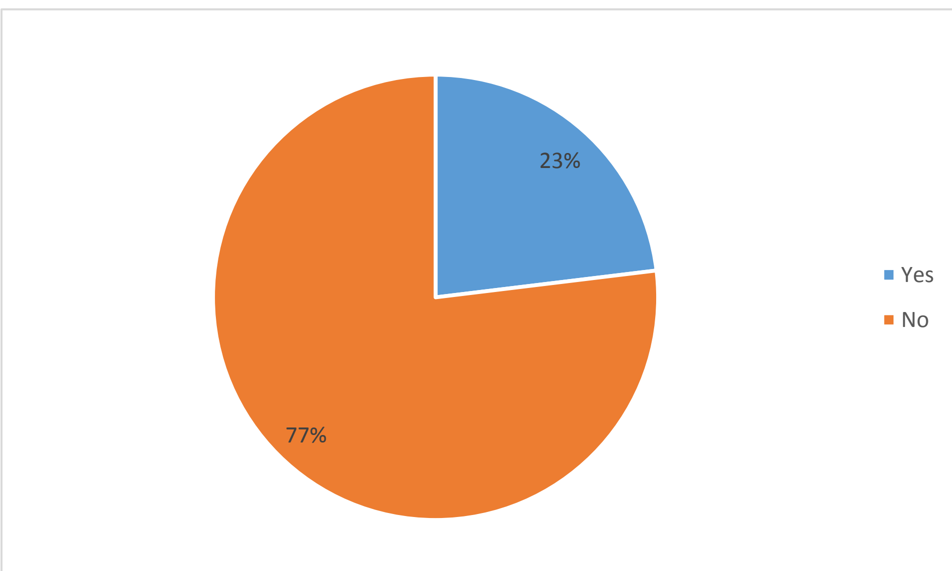


Figure 15 *The percentage of participants who use PGRs on secondary roads.*

Regarding the question of when PGRs are applied to roads, 9 out of the 14 interview participants provided a response (listed by division number; see below table). Across all interview participants, the two most common months to apply PGRs to road sides were March and April (both included 6 interview responses). June was the next most common month to apply PGRs (3 responses), followed by May and July (2 interview participants each). Last, January and February were only mentioned by one interview participant each as the months in which PGRs are applied to road ways. Table 19 displays the times of year in which division engineers have reported that they apply PGRs to roadways.

Table 19 *Times of year in which PGRs are applied to roads, by each division of NC.*

Division	Jan	Feb	March	April	May	June	July
1							■
2					■	■	■
5	■	■	■	■			
6						■	
7			■	■	■	■	
9			■	■			
11			■	■			
12			■	■			
13			■	■			

Question 3: In your opinion, does the use of PGRs reduce the necessary number of mowing cycle(s)? If so how many?

Thirteen out of 14 of the interview participants provided a response to this question. Nine said that, yes, using PGRs reduces the number of mowing cycles needed (divisions #1-5, 7, 9, 11, 13), 2 said that applying PGRs does not reduce the necessary number of mowing cycles (divisions #6 and 14), and 2 said that the answer depends on the weather conditions as well as the number of mowing cycles (divisions #8 and 12). This shows that most of the interview participants believed PGRs to inhibit plant growth and thereby reduce the number of mowing cycles that are needed to maintain roadside vegetation. This data is shown in Figure 16.

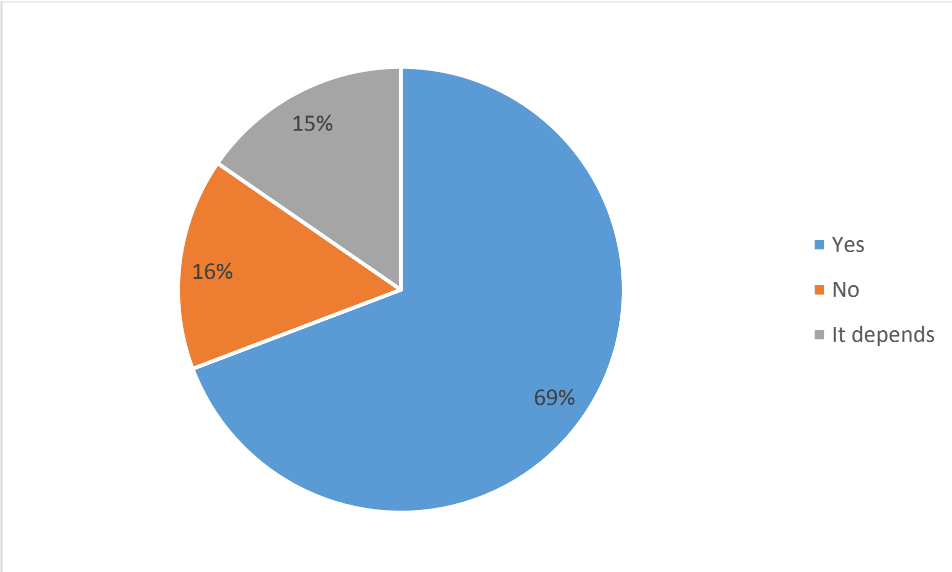


Figure 16 *Percentages of participants who believe that PGRs reduce the number of mowing cycles, as well as those who said 'it depends.'*

Ten out of the 14 interview participants responded to the question regarding the number of mowing cycles that can be reduced by using PGRs (see Table 20; listed by division). The most common responses, with two responses each, include a reduction in 1 to 2 mowing cycles following the use of plant growth regulators. All of the other amounts, including 0-1, 2+, 1-3, and 3, were only mentioned by one person during interviews.

Table 20 *The number of mowing cycles that division roadside environmental engineers believe can be reduced by using PGRs*.

Number of cycles	Division numbers
0-1	8
1	4, 9, 11, 13
2	2, 7
2 or more	1
1-3	5
3	3

Question 4: On average, how many mowing cycles are performed per year?

For interstates, 12 interview participants provided responses regarding the number of mowing cycles completed yearly. 5 of the interview participants said that they complete 4 mowing cycles per year (divisions #3, 5, 7, 12, 14). Three of the interview participants said that they complete 5 mowing cycles annually (divisions #6, 10, 11). One responded that 2 mowing cycles are completed yearly (division #4), 1 responded that 3 mowing cycles are completed yearly (division

#9), and 1 responded that 4-5 mowing cycles are completed every year (division #8). One said that 2-4 mowing cycles are completed annually (#13), 2 for warm season grasses and 4 for Fescue. This shows that the majority of the interview participants to complete 4 mowing cycles on interstates within their divisions, with 5 cycles being second most common. Figure 17 displays the number of mowing cycles completed on interstates as reported by division engineers.

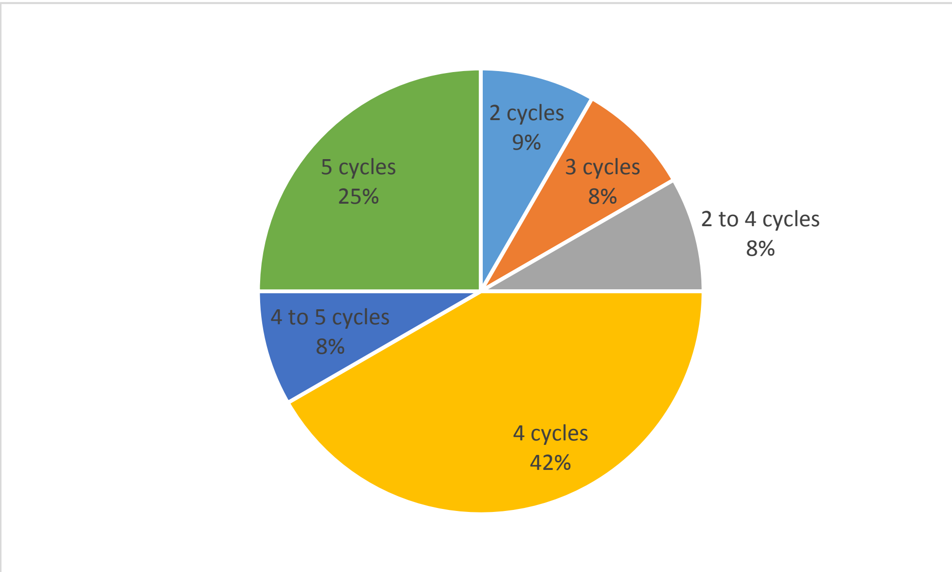


Figure 17 *Percentages of the number of mowing cycles completed yearly on interstates.*

For primary roads, 12 interview participants provided responses. Three interview participants said that they complete 4 mowing cycles every year (divisions #2, 5, 14). Three interview participants said that they complete 3 mowing cycles annually (divisions #1, 9, 13), and 3 interview participants stated that they complete 5 mowing cycles yearly (divisions # 6, 10, 11). One interview participant said that 2 mowing cycles are completed annually (division # 4). One interview participant stated that 3-4 mowing cycles are completed every year (division #12), and 1 interview participant said that 4-5 mowing cycles are completed annually (division #3). This shows that on primary roads in North Carolina, it is most common to complete 3-5 mowing cycles yearly; all have 3 divisions that reported this. Figure 18 displays the number of mowing cycles completed on primary roadways as reported by division engineers.

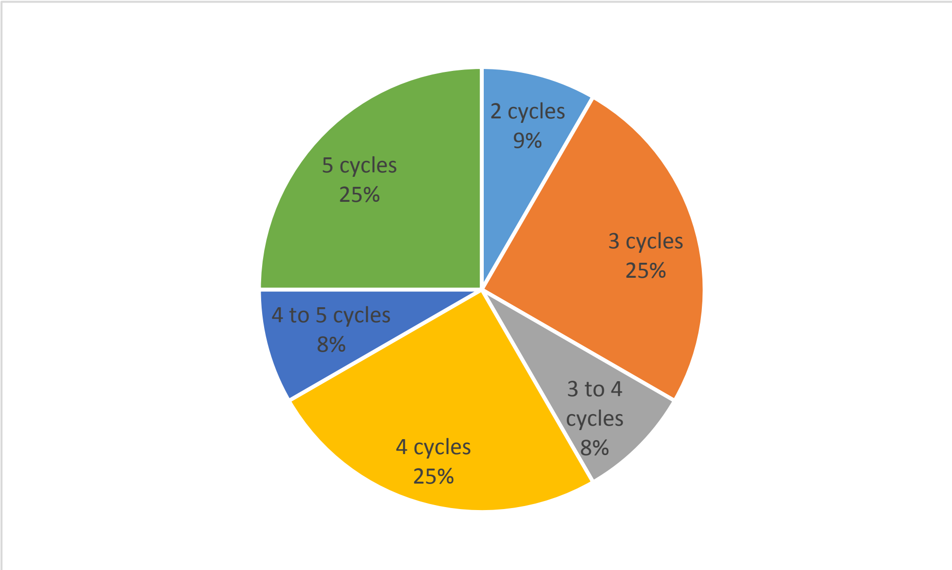


Figure 18 *Percentages of the number of mowing cycles completed yearly on primary roads.*

For secondary roads, 12 interview participants provided responses. 5 interview participants stated that 5 mowing cycles are completed annually (divisions # 1, 4, 5, 6, 10). Four interview participants said that 4 mowing cycles are completed annually (divisions # 2, 11, 12, 14), and 2 said that 4-5 mowing cycles are completed every year (divisions # 3 and 9). One said that 3 mowing cycles are completed annually on secondary roads (#13). This shows that on secondary roads in North Carolina, 5 mowing cycles are most commonly completed, followed by 4 cycles. Figure 19 shows the number of mowing cycles completed on secondary roads as reported during interviews.

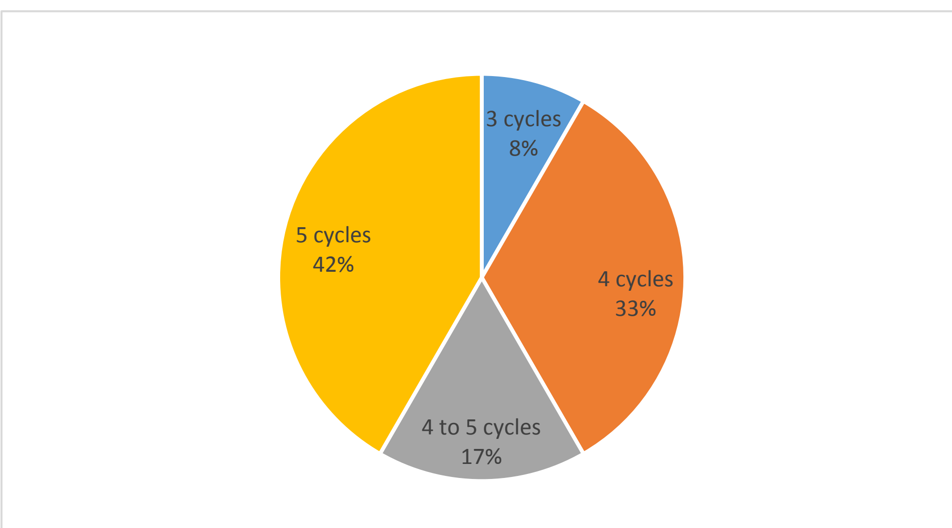


Figure 19 *Percentages of the number of mowing cycles completed yearly on secondary roads.*

Question 5: Do you administer turf mowing contracts in your Division? If not, who does?

All 14 interview participants provided information regarding parties responsible for administering turf mowing contracts within their respective divisions. Ten responded that they are the ones responsible for administering turf mowing contracts in their respective divisions (divisions #1-6, 9, 11, 12, 14). Two replied that the party responsible for administering turf mowing contracts is in transition (divisions #7 and 8). *The division 10 representative is the only one that differentiated the answer by type of road. The representative from division 13 mentioned that Roadside Maintenance is still responsible for mowing contracts, and that there is better coordination than there had been in the past; the division 13 interviewee also mentioned that there is currently no plan for Roadside Environmental to inspect contractors.*

[Included in the section on contracts: "In North Carolina, almost all of the divisions have made the administrative transition from Roadside Maintenance to the Roadside Environmental Unit for litter and vegetation management (divisions #1-6, 9, 11, 12, 14). Divisions 7 and 8 explained that the party responsible for mowing contracts is currently in transition. While division 13 still has Roadside Maintenance administering mowing contracts, in division 10 there is collaboration between Roadside Maintenance and Roadside Environmental in the administration of mowing contracts."]

The representative from division 7 replied:
"This is my first year administering mowing contracts. We are currently transitioning from the maintenance unit this year. The Maintenance UNIT has performed the mowing and other mechanical operations in the past years we are currently transitioning the operation over to my department the transition should be completed by the end of this year."

The division 8 representative stated that "we are currently transitioning to administer mowing contracts. In the process of hiring inspectors and training them to take over from county maintenance."

One interview participant stated that they are responsible for administering some of the turf mowing contracts (division #10): "I administer them on Primary and Secondary routes in 4 out of the 5 counties in our division. The Maintenance unit in the 5th county mows their own, and the Interstate Maintenance Unit maintains the interstates."

Out of the 14 interview participants, 4 provided information regarding other parties responsible for turf mowing contracts other than themselves. One said that the responsibility for mowing contracts still rests with the Roadside Maintenance department. Three said that this responsibility is currently in transition; out of these 3, 1 person said that the responsibility is transitioning from maintenance to their department, and 1 person said that the responsibility is transitioning from county maintenance to inspectors.

Question 6: Do you apply Broadleaf Control chemicals? If so how often and when?

All 14 divisions indicated that they use Broadleaf Control chemicals. Out of 14 participants, 10 responded with information regarding how often Broadleaf Control chemicals are used. This information is displayed in the table below and includes the division numbers. The representative for division number 12 differentiated their answer based upon the type of road; specifically, he/she said that interstates are treated with Broadleaf Control chemicals twice per year, while primary roads are treated with Broadleaf Control chemicals once per year. Six interview participants apply Broadleaf Control chemicals once per year, 2 reported applying Broadleaf Control chemicals 1-2 times per year. One person said that he/she applies broadleaf chemicals once every 2-3 years, and 1 said twice per year. The representative from division 13 stated that he/she may not get around to all secondary roads. Table 21 displays the interview responses from each of the divisions regarding the frequency with which Broadleaf Control chemicals are used.

Table 21 *How often Broadleaf Control chemicals are used*.

Occurrence	Division No.
Once every 2-3 years	10
Once per year	4, 7, 8, 9, 11, 13
1-2 times per year	3, 12
Twice per year	14

Seven out of the 14 participants provided information regarding the time frames in which Broadleaf Control chemicals are applied within their divisions. Table 22 displays this information by division number. The time frames are approximate. For example, division number 12 responded that Broadleaf Control chemicals are applied during the spring and late summer. Out of all responses, May and June were noted as the most common months in which Broadleaf Control chemicals are applied to roadsides (6 responses each). Following May and June, April and July were next most commonly mentioned (2 responses each). March, August, and September were the least frequently mentioned by interview participants, with one response each.

Table 22 *Time frames in which Broadleaf Control chemicals are applied by division number*.

Division No.	March	April	May	June	July	Aug	Sept
2			■	■	■		
4			■	■	■		
5			■	■			
7		■	■				
8			■	■			
9				■			
12	■	■	■	■		■	■

Although the question was not specifically asked of interview participants, many people provided information regarding the type of broadleaf chemical application used to control broad leaf weeds. Out of 14 total participants, 5 provided information about the types of broad leaf weed control used. They all provided different answers so were not grouped into categories. The representative from division 1 said that they use Confront, division 2 listed WSR 2.0, division 5 listed Garlon 3A Triclopyr, division 6 listed 24D “and others,” and division 12 listed (1) 2D and (2) Element 3A. The representative from division 1 was the only division that provided information about the specifics of its chemical application: "[Confront] is added to the SFM75 mixture at 28 oz/Ac."

Question 7: What kind of special treatments or procedure is used for control around fixed objects? (guard rail, cable barrier, signs, bridge ends, etc.).

As is displayed in Table 23, 10 interview participants reported using selective chemicals (divisions #1, 2, 5, 6, 7, 8, 11-14) and 6 reported using non-selective chemicals to control roadside vegetation within their divisions (divisions #1, 3, 4, 7, 10, 12). Out of the selective chemicals mentioned, 4 mentioned plant growth regulators (divisions 5, 6, 8, 12) and 4 mentioned chemicals with triclopyr as the active ingredient (divisions #1, 2, 7, 12); out of these, 2 specifically mentioned Element 3A, 1 mentioned Garlon, and 1 mentioned triclopyr in general. One person mentioned 2D, which is a selective chemical used to control vegetation, under the "other" category. Non-selective chemicals used for roadside vegetation management include chemicals with glysophate as the active ingredient (divisions 1, 4, 7) as well as chemicals like Round Up.

Following the use of chemicals, mechanical methods were the most commonly mentioned approach to controlling roadside vegetation around fixed objects (divisions #2, 3, 9). Following this, sprayers were mentioned twice (divisions #3, 8), and surfactants are mentioned twice (divisions #2, 7). Out of the 12 interview participants, 10 provided additional information under the "other" category that could not be grouped into existing categories (all except for divisions 1 and 14). The following were listed under the "other" category: prodiamine, Rodeo, Esplanade (2), basic grass control, WSR, broadleaf weed control (2), pre-emergent, herbicide mix, chemicals, Round Up, Confront, Krenite, and 2D.

Table 23 *The types of treatments and procedures used to control vegetation around fixed objects*.

Div.	Selective Chemicals	Non-Selective Chemicals	Mechanical	Sprayers	Surfactant	Other
1	X	X				
2	X		X		X	Prodiamine, Rodeo, Esplanade
3		X	X	X		basic grass control
4		X				WSR [Warm Season Release]
5	X					Broadleaf weed control
6	X					pre-emergent, Broadleaf weed control
7	X	X			X	Esplanade
8	X			X		herbicide mix
9			X			chemicals
10		X				Roundup, Confront
11	X					
12	X	X				2D
13	X					Krenite
14	X					

Figure 20 displays the percentage of interview participants that use selective chemicals (divisions # 1, 2, 5, 6, 7, 8, 11-14) versus those that use non-selective chemicals to control roadside vegetation (divisions #1, 3, 4, 7, 10, 12). Many of the interview participants use a combination, which is why 10 of the responses mentioned selective chemicals, and 6 of the responses mentioned non-selective chemicals, even though only 13 interview participants provided information as to whether selective or non-selective chemicals are used. This is due to multiple responses. As is shown in the pie chart, 62% of the chemicals mentioned were selective in nature, and 38% were non-selective in nature.

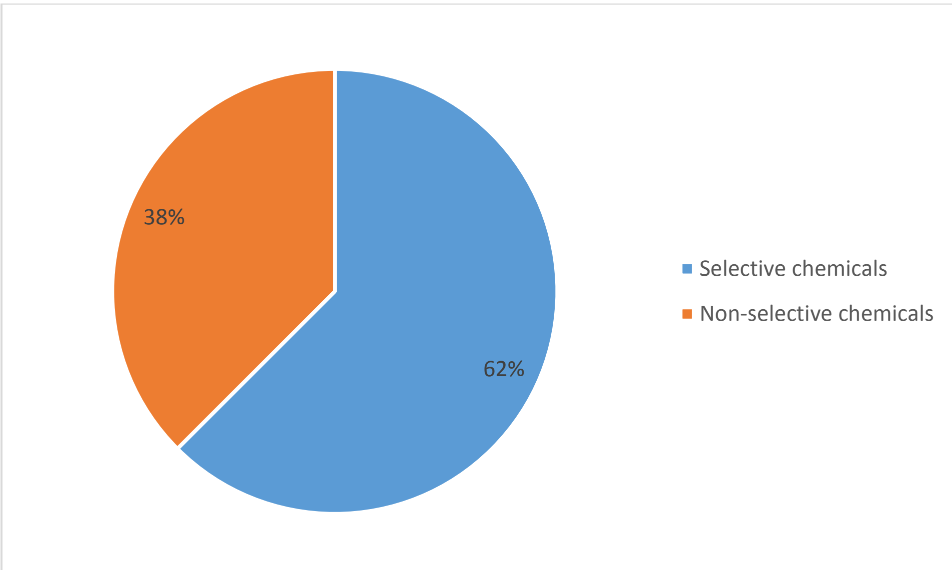


Figure 20 *The percentage of interview participants that use selective chemicals versus those that use non-selective chemicals (n=16 mentions; 13 interviewees).*

Figure 21 displays the most commonly mentioned types of treatments and procedures used to control vegetation around fixed objects alongside roadways. Aside from the “other” category (11 mentions out of 34; 32%), the most common approach mentioned is selective chemicals (10 mentions; 29%), followed by non-selective chemicals (6 mentions; 18%), mechanical (3 mentions; 9%), sprayers (2 mentions; 6%) and surfactants (2 mentions; 6%).

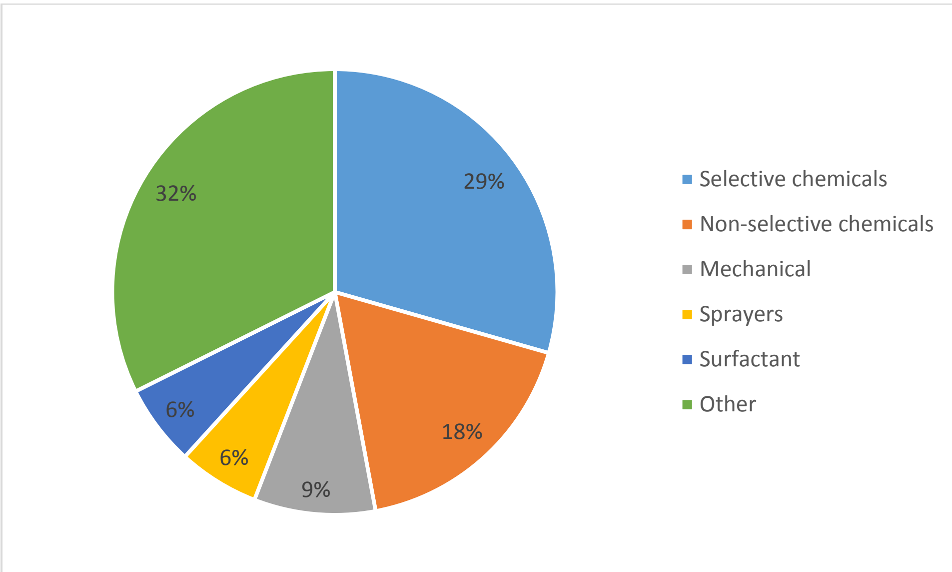


Figure 21 *Treatments and procedures used to control vegetation around fixed objects (n=34 responses and 14 interviewees), with selective and non-selective chemical treatments distinguished.*

Figure 22 displays the most commonly mentioned types of treatments and procedures used to control vegetation around fixed objects alongside roadways, with selective and non-selective chemical approaches categorized together under “chemical applications.” Aside from the “other” category (11 mentions out of 31; 36%), the most common approach mentioned is chemical applications (13 mentions; 42%), followed by mechanical (3 mentions; 10%), sprayers (2 mentions; 6%) and surfactants (2 mentions; 6%). This shows that chemical and mechanical applications are the most prevalent.

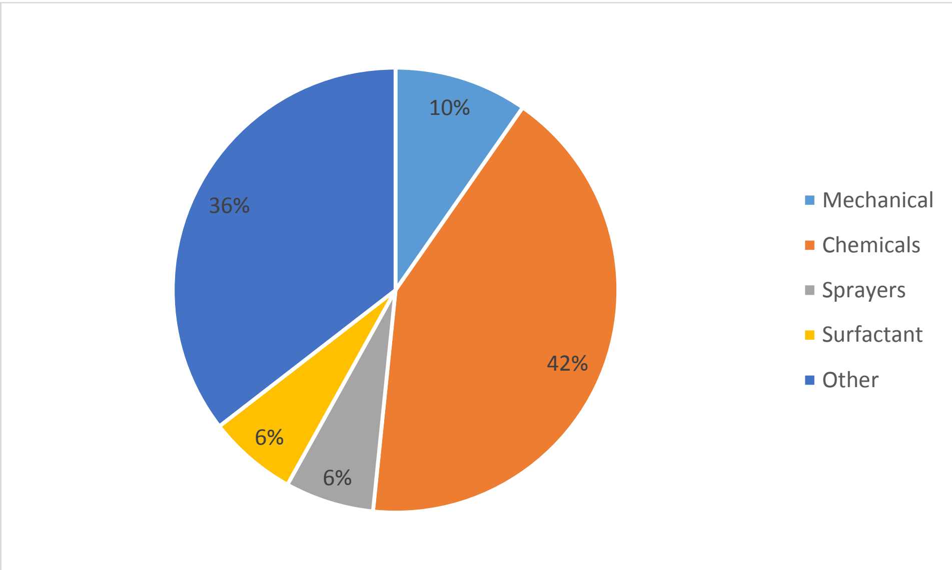


Figure 22 *Treatments and procedures used to control vegetation around fixed objects (n=31 mentions; 14 interviewees), with selective and non-selective chemicals grouped together.*

Question 8: What chemical treatment is utilized for wooded species control?

Table 24 displays the responses regarding the types of treatments applied to roadside vegetation to control wooded species. More than one X in a category indicates that multiple examples of that chemical type were listed by one interview participant. The number of examples of chemicals with Triclopyr as the active ingredient (n=21 responses) were mentioned by 12 interviewees out of the 14 who provided a response to this question. Examples of chemicals listed under this category include Garlon, Garlon 3A, Garlon 4, Element 4, Garlon 4E, Garlon 4A, Element 3, and Element 3A.

Krenite (n=7 responses and 7 interviewees), Patron 170 (n=4 responses and 4 interviewees) and crop oil (n=3 responses and 3 interviewees) were also mentioned. Three interview participants mentioned other examples that were not categorized (n=4 responses); these included: surfactant, Polaris brush control, dormant stem, and triamine.

Table 24 *The types of treatments and procedures used to control wooded species*.

Division No.	Triclopyr	Krenite	Crop oil	Patron 170	Other
1	XX				
2	XX	X	X	X	Surfactant
3					Polaris brush control
4	XXX			X	
5	X				
6	XX	X			
7	X	X	X		Dormant stem, Triamine
8	X	X		X	
9	XX				
10	XX		X	X	
11		X			
12	XX	X			
13	X	X			
14	XX				

Figure 23 displays the types of treatments and procedures used along roadways to control wooded species. Chemicals used most often include those with Triclopyr as the active ingredient (n=12 responses and 12 interviewees; 42%), followed by Krenite (n=7 responses and 7 interviewees; 24%), Patron 170 (n=4 responses and 4 interviewees; 14%), crop oil (n=3 responses and 3 interviewees; 10%), and other (n=3 responses; 10%). This shows that Triclopyr is the most commonly used approach, followed by Krenite.

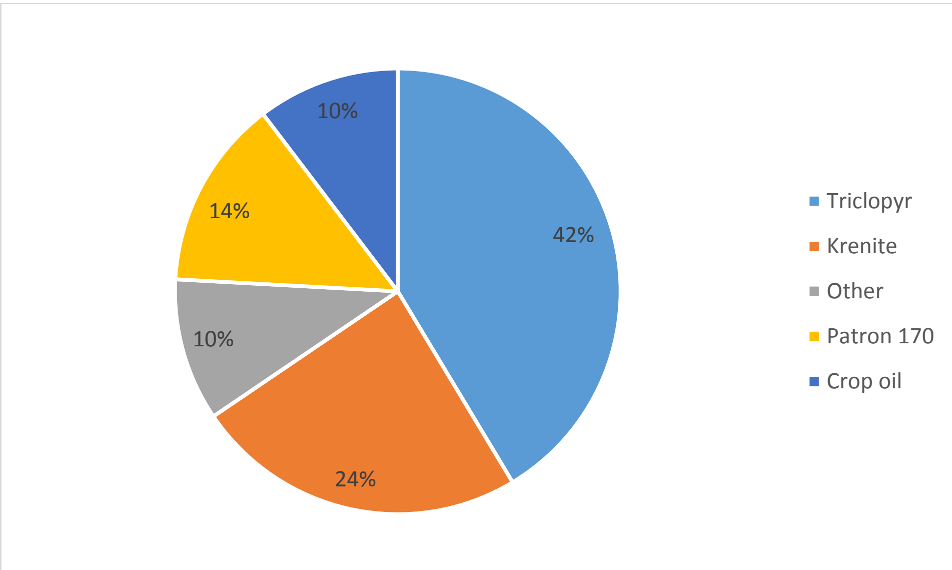


Figure 23 *The types of treatments and procedures used to control wooded species (n= 29 responses and 14 interview participants).*

Question 9: How is that treatment coordinated with mechanical wooded species control?

All 12 interview participants provided a response to this question. Table 13 displays the responses as well as the division numbers of respondents. Ten of the responses indicated that a trim followed by a chemical application is the method used. One of the respondents responded that a trim is completed of the wooded species followed by brush/limb treatment/de-limb. One of the respondents said that he/she alternates trimming and chemical application by seasons, as well as alternating the types of chemicals used. Table *25* reveals that the vast majority of interview participants reported that they complete a trim followed by a chemical application in order to control wooded species near roadways.

Table 25 *How chemical treatment is coordinated with mechanical wooded species control*.

Method	Divisions
Trim followed by a chemical application	1, 2, 4, 5, 7, 8, 9, 10, 11, 12, 14
Trim followed by brush/treatment of limbs/de-limb	3
Alternate trim and chemical application by seasons; alternate types of chemicals used	6
Trim followed by a chemical application within one year	13

Question 10: Other comments

One comment was provided by the representative for division 1: "we do not maintain any interstate systems in our Division. Division 4 maintains the small section of I95 that runs through Division 1."

The representative for division 11 described the structure of the division as follows: 22 staff, including 2 herbicides, 1 seed crew, 1 planting and plant bed maintenance; 6 inspectors, who monitor the work of contractors [3 turf mowing inspectors & 3 long arm mowing inspectors]. The division 11 representative also explained that Broadleaf control is applied with PGRs. Six years ago, zoysia grass was planted around cable rails (2-16 inch strips), which are given one pass of the weed eater in the fall; I-77 is not applied since there is established turf.

The representative for division 13 also explained the structure of his/her division: Currently there are 25 positions with 6 vacancies; there used to be 42 positions. There are four crews, one focusing on the plant bed, two focusing on erosion control, and one focusing on the herbicide/wildflower program.

Follow-up to initial interviews: Barriers to Increasing PGR Use

NCDOT roadside divisions were contacted to follow-up on completed interviews. Division representatives were asked about barriers that they face to increasing the number of applications of PGRs. Multiple responses by the same interviewee were coded separately, which is why there is a column for the number of responses as well as the number of interviews that supported a given theme in Table 26.

Table 26 *NCDOT division responses to barriers to increasing the number of PGR applications.*

Barrier	Description	Example Quote	Reponses	Interviews
Personnel	This code involves needing more staff/manpower	n/a	11	10
Budget	This code refers to needing more funding	n/a	10	8
Equipment	This code refers to needing additional supplies	"[We would need] spray trucks, applicators, chemicals, secondary required equipment" (div. 10)	10	6
Timing	This refers to having a limited amount of time for spraying to be effective	"[There is a] small window for spraying Fescue" (div. 11); "Summer spraying [is] ineffective" (div. 5)	8	6
Other	This refers to any barrier mentioned that did not fit into the above categories	"Adding additional herbicide applications would drop the level of service on other responsibilities" (div. 3)	6	4

As depicted in Table 26, the five main barriers to increasing their use of PGRs included personnel, budget, equipment, timing, and other reasons; descriptions of each code is included in the figure as well. Lacking the amount of personnel needed to increase PGR use was most frequently mentioned, with 11 responses relating to this theme; ten interviews supported this theme. The next most common theme mentioned was budget. Ten responses, and eight interviewees, included this theme.

Needing more equipment was the third most commonly mentioned barrier to increasing PGR use, with 10 responses and 6 interviews supporting this theme. Examples of this code include “[We would need] spray trucks, applicators, chemicals, secondary required equipment” (div. 10) and “we need one more truck” (div. 3). Timing as a barrier to increasing PGR use was mentioned by the same number of interviewees as the “equipment” code (6), but had fewer total responses

(8). Examples of how timing can be a barrier to increasing the use of PGRs include the following:

- “[There is a] small window for spraying Fescue" (div. 11)
- "Summer spraying [is] ineffective" (div. 5)
- “Have mostly Fescue which is applied between March 15 and April 15” (div. 9)

Lastly, barriers to increasing PGR use by division representatives that did not fit into any of the categories discussed were coded as “other.” Other barriers were mentioned by 4 interviewees with a total of 6 responses. The responses coded as “other” included the following:

- “Adding additional herbicide applications would drop the level of service on other responsibilities" (div. 3)
- "[A PGR application] doesn't always work (e.g. wet season)” (div. 1)
- “Aesthetic concerns” (div. 1)
- “[NCDOT] would need to construct a PGR program that maps the nuances (turf type, soil type, weed pressure, water table)” (div. 1)
- "More research is needed on multiple PGR applications” (div. 7)
- “[It is] hard to justify adding more staff when there is no work for them the rest of the year” (div. 11)

NCDOT divisions were also asked whether they would increase the number of PGR applications if the barriers listed were overcome. In response, the 13 total interviewees either responded yes (7) or no (6). Five of these division representatives also explained that they would increase the amount of area that was treated with PGR use; out of the five interviewees that would expand the amount of area covered by PGRs, two had responded that they would not increase the number of PGR cycles, and three indicated that they would also increase the number of PGR cycles. Figure 24 depicts the total responses in a pie chart (18 responses from 13 interviewees). Two examples of quotes where division representatives indicated that they would increase the number of PGR cycles used if barriers were overcome are displayed below.

- "We may increase the NUMBER of applications by 1" (div. 2)
- "[We] currently we do not use any PGRs but if we did have the necessary resources to use them extensively we would probably do so" (div. 4)

Six division representatives indicated that they would not increase the number of PGR cycles and most of them stated “no.” A more extensive example of this code is as follows: "With unlimited resources, I still do not think I would pursue additional SVR treatments" (div. 11).

Five interviewees mentioned that they would expand the amount of area covered by PGRs if barriers were overcome. All five of these quotes are listed below.

- "We would increase the amount of area treated with one or two applications" (div. 2)
- “[We] would expand the WSR and PGR program by 1,500 shoulder miles” (div. 1)
- “If we had the funding and manpower, we would increase our PGR applications to two a year and include all Primary routes and if possible start working sections of secondary’s throughout the Division.” (div. 6)
- “[We] would apply PGRs to more routes (currently only 1 route)” (div. 10)

“[We] would provide two WSR treatments per year on all primary routes (divided and undivided)” (div. 3)

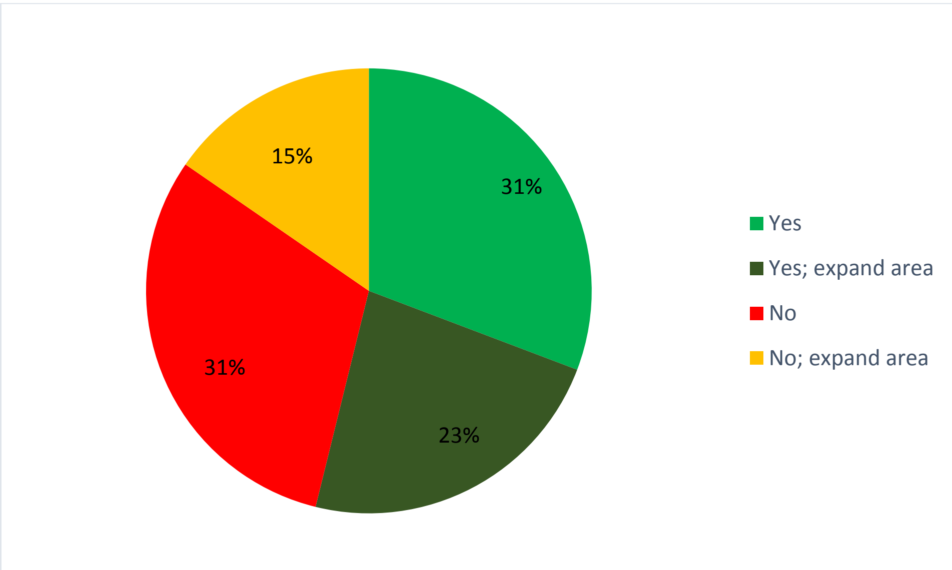


Figure 24 *The number of responses to whether the number of cycles of PGRs would be increased if barriers were overcome.*

Out of the 13 total interviews completed, seven interviewees said that they would increase the number of PGR cycles currently used on roadways. These seven NCDOT division representatives were also asked how many PGR cycles they would use if they could. Out of the 7 interviewees who provided information for this question, five interviewees responded that they would increase their PGR use to 2 cycles. One interviewee would increase PGR use to 1-2 cycles, and one mentioned that they would increase PGR use to one application cycle. This is depicted in the form of a pie chart in Figure 25.

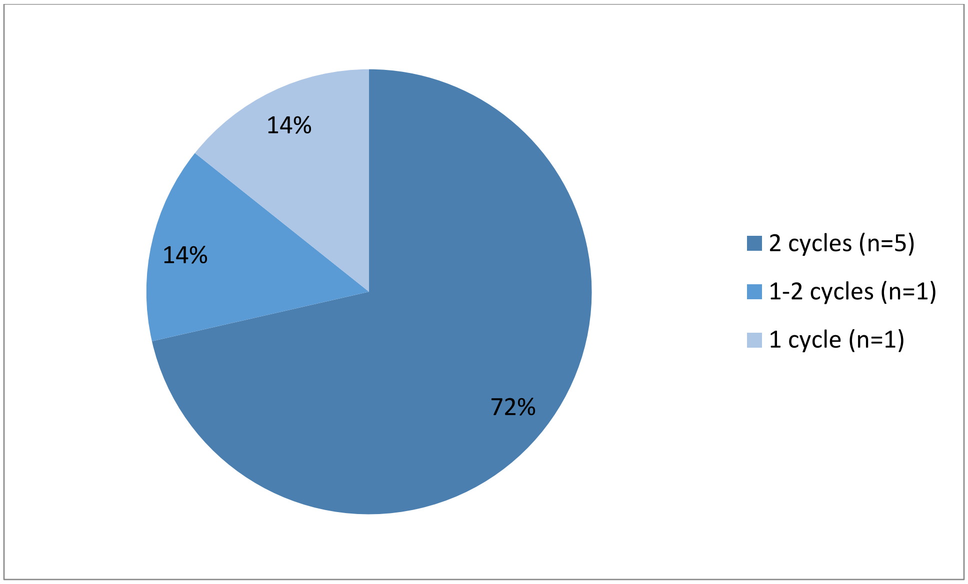


Figure 25 *The number of PGR application cycles that NCDOT division representatives reported that they would implement if barriers were overcome.*

Out of the seven interviewees who reported that they would increase their use of PGRs if possible, five reported to be currently using one cycle of PGR applications, and two reported that they did not currently use PGRs in their divisions. Taking into account the current number of PGR application cycles in use in each of these seven divisions relative to their desired number of PGR cycles, Figure 26 is displayed below to show the desired increase in PGR cycles as reported in interviews. Out of these seven divisions, six showed a desired increase in PGR use by one cycle (i.e. either from zero to one or from one to two); one division representative reported a desired change of 1-2, from a current level of no regular PGR use.

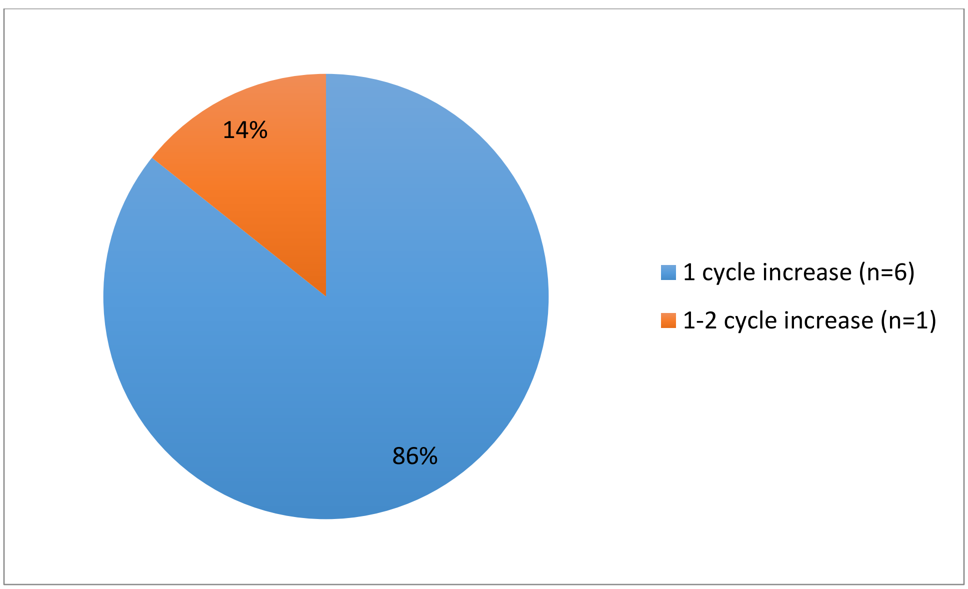


Figure 26 *The desired change in terms of PGR cycles, comparing the current level of PGR use in each division to the reported number of PGR cycles that each division would like.*

Conclusions from Interviews

This analysis of barriers to increasing the use of PGRs on NC roadways shows that personnel, budget, equipment, and timing were the most commonly mentioned by NCDOT division representatives. Out of 13 total interview participants, it was also found that slightly more than half of NCDOT division representatives (n=7; 53.85%) would increase the number of PGR cycles used, and slightly less than half (n=6; 46.15%) would not increase the number of PGR cycles. In addition to these responses, five of the 13 interviewees (38.46%) mentioned that they would expand the area covered by PGRs if barriers to implementation were overcome.

Five of the seven interviewees who would increase the number of PGR application cycles indicated that they would increase the number to 2 cycles. One reported that they would implement 1-2 PGR cycles, and one said that they would administer one PGR cycle. Finally, out of the seven interviewees who indicated that they would increase the number of PGR cycles if barriers were overcome, six would increase the number of cycles by one, and one person reported that they would increase the number of PGR application cycles implemented by 1-2.

As has been noted in the literature review section, application of PGRs is a more cost-effective solution to vegetation management than morning. The data presented above clearly indicates that most divisions in NC DOT currently perceive several barriers to increasing the number of PGR applications, primarily having to do with budget and personnel but also because of compressed time windows. If such barriers, especially with regards to budget, equipment and personnel can be addressed by NC DOT, some divisions would increase the number of PGR applications by one additional cycle. Based on the analysis of the overall average associated costs, increasing PGR use by one cycle is expected to save NC DOT an annual sum of $758,461.83 if the seven divisions who stated that they would increase the number of PGR cycles did so, and $1,516,923.66 if all 14 divisions increased their PGR use by one cycle.

Vegetation Management Practices obtained from Benchmarking with Peer States

ALDOT: "Roadsides are mowed from 2 to 4 times annually depending upon the average daily traffic count or local activity interest; guardrails / cable rails are trimmed as needed as a part of the scheduled mowing cycle. Each mowing is typically followed by a turf broadcast herbicide treatment designed to control or delay the regrowth of broadleaf weeds and to provide seed head suppression of grasses. Specific treatments are made as required for the control of perennial grasses such as Johnsongrass or Cogongrass. Side trim and other brush control applications are generally restricted to the fall"

TXDOT: Herbicidal applications and mowing - "Spraying is done in-house, staff are trained, including as to the chemicals that are acceptable to use. The supervisors in charge of herbicidal applications are all licensed. TX DOT doesn't use PGRs because they work on some species but not others; instead, they use a mixture of selective and non-selective chemicals. Mowing takes place 2-3x/year (urban: 3; rural: 2)." For herbicide treatments at the TXDOT, there are typically 1-2 applicators in rural counties, and 7-8 applicators in urban counties.
Guardrail & fixed object: Concrete pad around, spray trucks, herbicides, add grass, weed eating 3x/year
Broadleaf: Wildfires drive our program; to controls species like bloodweed and other brush species, the herbicides Escort, Dista, Transline, Pathfinder II and Capstone are used. Long arm mowing is also used.

The following were provided as examples of vegetation management practices followed by the KYDOT: "Mechanical mowing, herbicide application, weed bio-control, fertilization, seeding, ditching." Furthermore, KYDOT specified that "all roadside turf is mowed at least 3 times per year and applied once for broadleaf weeds and once for noxious weeds. All guardrail, traffic islands, cable guardrail, and barrier wall is applied at least once per year."