INVASIVE PLANT SPECIES ALONG ROAD SEGMENTS AND RECOMMENDATIONS FOR REMEDIATION

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ABSTRACT

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This literature review specifically looks at roads segments as facilitators for non-native invasive plant species. There are three types of roads presented throughout this paper; primary regionally paved roads; secondary local roads; and tertiary unpaved off-road segments. The goal is to review and recognize any predictable patterns of spread along these three types of roads, so that appropriate restoration efforts can be implemented. To review such a topic, several academic articles all containing a focus on invasive plant species along road corridors were gathered and organised into groups based on the type of road that was mentioned in the article. All the data covering species richness was organized into a table and analysed. Ultimately the results displayed that primary roads were the least successful at facilitating spread for invasive plant species and tertiary roads were most successful. Many variables like soil quality, temperature, traffic, etc. can provide explanation to why species richness is more abundant on tertiary roads than primary roads. Based on the compiled explanations from an array of literature, an appropriate conservation management technique such as leaving cuttings on site, cutting/ pulling invasive plants at a certain time as well as introducing wash stations on suitable site. This will encourage the reduction of unwanted invasion and ensure the efficiency of conservation practises.

Keywords: density, flora, habitat, non-native plant species, paved, vehicle, road corridor, restoration, saltation, soil, species richness, vegetation.

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First and foremost, I would like to acknowledge my thesis supervisor Jian Wang for guiding me in the development of my thesis topic and research. I would also like to acknowledge the multiple sources gathered and used within this report, without these I would not have any data backing up my statements. I would also like to acknowledge Dr. Lense Meyer and Dr. Kevin Crowe for their help in constructing my thesis review. Finally, I would like to acknowledge my class mates that have encouraged and motivated me to complete my thesis. Without any of these supports I would not have been able to finish the report when I did. Thank you all.

1.0. INTRODUCTION

Roads are a necessary service not only for the transportation needs of people but also their industrial goods and resources. All countries rely on road networks for trading purposes between nations. Imports and exports of goods allow for a country to develop and thrive in areas where they would struggle without the connection and ability to trade resources with others. The value of a community is dependent on how accessible it is via road networks. Without roads, travelling long distances would be very difficult and inefficient for people (Gonzales-Feliu *et al.*, 2012).

As the human population expands, more native terrestrial ecosystems will become vulnerable to human modification through the construction of roads. This allows opportunities for flora species to propagate along road verges, which provides access into new territories that would otherwise be out of their range (Mortensen *et al.*, 2009). Undermanaged roads are often taken advantage of by invasive plants, this is because roadside verges offer suitable habitats to facilitate their spread and infiltrate their hostile being into territory that is un-native to them. Other than the occasional natural disturbance, there are generally no direct threats on site to restrict the range of invasive plants and therefore become problematic to the native flora species. Invasive flora species tend to favour and exploit habitat conditions that native species do not favour, and with the continuous development of roads there is a higher density of unfavourable native species habitat which invasive species dominate (Hansen and Clevenger 2005).

Depending on the specific type of service the road functions as, the condition of the road and habitat quality will differ. There are three orders of roads explained within the literature, these are; primary, secondary and tertiary roads. All exhibit different characteristics and functions between each other and may display different rates of spread and richness of invasion of non-native plant species. Identifying variables like roadside soil, ditches, modes of hostile flora transportation, and road management techniques, will factor into the success rate of invasive plant species survival. Variability between geographic and biological plant species is important to keep note of and necessary to understand when performing this study.

Currently, roadside management is very limited. Conservation techniques to re-introduce native flora species and their suitable habitats is very difficult since there is a lot of data deficiency on the influence roads have on vegetation. There is no data that collectively explains the harm roads produce on vegetation and therefore conservation methods are still adapting to find the most suitable practice.

Understanding specific characteristics of each type of road will help predict the rate of invasion different non-native plant species display within a region. This will be helpful to rehabilitate natural native species back into their original habitat as well provide a basic understanding of proper roadside management.

1.1. OBJECTIVE

The purpose of this thesis is to compile, examine and review a set of recent literature that addresses the relationship between road characteristics and the spread of non-native plant species. One interest is to understand the rate of invasiveness certain species express on different road types and to determine which road conditions favour certain non-native flora species. Overall, this thesis will inform and convince the reader about the risk invasive plant species pose on the biological diversity in the area and consider the appropriate remediation efforts along different road types

1.2. HYPOTHESIS

The null hypothesis (H_0) states that there will be no difference (α= 0.05) between the rate of spread of non-native plant species among the three road types (A= 1,2,3). The p-value being used in this data collection will represent the difference of road conditions in a percentage (*i.e.*, the response variable).

A_1 = Invasive plant species richness in primary roads

A_2 = Invasive plant species richness in secondary roads

A_3 = Invasive plant species richness in tertiary roads

$A_1 = A_2 = A_3$ Equation [1]

The alternative hypothesis (Ha) states that primary roads will facilitate spread of non-native plants species the most, secondary roads will slightly facilitate spread of non-native species and tertiary roads will facilitate the survival of non-native plant species the least. This is based on the assumption that higher traffic will act as a greater means of facilitating spread of invasive flora species according to the literature review.

$A_1 > A_2 > A_3$ Equation [2]

1.3. LITERATURE REVIEW

1.3.1. ROADSIDE SOIL

Plants depend on sufficient soil nutrients to maintain a successful establishment along newly built roadsides; therefore, roadside soil is one of the the most important factor when considering the rate of spread of non-native plant species. A study done by Gelbard and Belnap (2002) showed that roadside characteristics such as soil pH, nutrients, depth, disturbance and topography are all factors that will influence the range of spread for invasive plant species along paved, improved surface, graded and four-wheel-drive tracks. Different roadside conditions are determined essentially by the purpose of the road, meaning that all roads constructed for a similar purpose will exhibit similar roadside characteristics. Another study done in 1997 defined roads into specific groups based on their usage; Primary, secondary and tertiary roads (Greenburg *et al.*, 1997). Each road type (primary, secondary and tertiary) will display different roadside habitat conditions compared to one another, but every road in the same order will exhibit similar characteristics. However, this is only true for roads constructed in similar ecoregions. Different biomes will have different conclusions on the rate of spread of plant species since different environments will have different soil types and characteristics. It could be also argued that standard road construction creates favourable habitats for invasive plant species since man alters the original soil type in order to develop a road (Wang and Yu 2017). The development of roads will allow for traffic to introduce and propagate invasive seeds onto disturbed roadside sites allowing higher concentration of invasion on newly constructed roads.

Vehicles will mostly be concentrated on primary roads which will lead to greater emissions of heavy metals both from tailpipe and non-tailpipe (*e.g.*, brake wear tire particulates) contamination in the area. These heavy metals, as projected in a study done by Khalid e*t al.* (2018), were found to settle and contaminate soils along with plants. Plants and soils in proximity to roads, displayed metal concentration that were 8-11 times more than plants and soils farther away from the road. This toxicity alters the plant ecology to some degree and may indicate that primary roads are likely to exhibit higher toxic environments due to more vehicles contributing to roadside contamination.

1.3.2. INVASIVE SEED DISPERSAL

For plant species to effectively survive within a new habitat, they need to develop and adapt to a method of seed dispersal that will benefit their continuous existence. Hotspots for alien species were discovered in a study across Germany and Austria. The study concluded that invasive plant species were abundant along side anthropogenic landscape such as road segments, railways and water ways (Benedetti and Morelli 2017). There is a correlation between anthropogenic landscapes and allocation of alien plant species, simply because construction of favourable habitat conditions allows for easy seed dispersal of invasive flora species in the area. This study is helpful in this literature search, since data collected on hotspot species density along different road segments will determine which type of road facilitates the most spread. Although road and railway segments contain favourable habitats for alien species, road segments also support a higher species richness. This is because there is more traffic on roads and alien plant species like to use vehicles as a vector to assist them in long distance transportation. (Hansen and Clevenger 2005). Vehicles that travel on unpaved roads are found to be most susceptible of being a vector of non-native seed dispersal (Rew *et al.*, 2018).

Most of the literature reviewed, examined specific species to determine how they travel, and so far, the results show that most alien flora species strongly favour paved roads. For instance, a study on ragweed concluded that this particular species favours paved roads since it relies on vehicle traffic to facilitate its spread (Joly *et al.*, 2011). Another shows that smooth bedstraw species abundance increases within 125m of a paved road (Meunier *et al.*, 2018).

On the other hand, there are also results that show spread of invasion along forestry roads. In a study conducted in 2008, forest roads within a 32,000ha forest that was at least 250m away from the main road did a patch experiment to determine the spread of invasion within different habitat types within the forest. Results showed that *Microstegium vimineum* strongly favoured roadside conditions nearby wetland or forest type habitats and took advantage of the corridor to facilitate its spread (Mortensen *et al*., 2008). Another study that focused on *Celastrus orbiculatus* (Asian Woody Vine) concluded that this species prefers conditions on logging road due to the significantly higher soil pH (Silveri *et al.*, 2001). Meaning that it is likely to travel on verges that exhibit higher pH readings.

The location of the road is crucial for the survival of most alien plant species. Roads that were constructed along ridges or valleys will predict patterns for a different vegetation. A road that is placed within a shaded area for instance will likely provide inadequate habitat for most vegetation simply because not all invasive species are shade tolerant (Douglas *et al.*, 2009). The defined placement of the road will advocate a predictable pattern of the distribution of alien vegetation in the area. Going off this statement, an article on human road infrastructure studied which plant species occurred on roadside soil. The study organized road types by order; primary, secondary, and tertiary and concluded that plant distribution followed a pattern that suggests that natural and anthropogenic environmental factors can stress the native flora species allowing for invasion to occur at different rates depending on the road type (Manier *et al.*, 2014). This is important for control management of invasive plant species.

1.3.3. ROADSIDE MANAGEMENT

Conditions that occur along roads tend to favour non-native plant species and therefore, to reduce invasion, it is important to understand affective roadside management techniques. A study done in New England found that smaller towns will have fewer damaging effects from invasive species since these urban areas are isolated (Barton et al., 2003). This means that the design of smaller towns is a type of management technique to control invasive plant species spread. There is a lot of time and money that goes into roadside management, however it is uncertain whether the affects are worth the results. A study done in 2016 focuses on just that; whether the management practises are worth the time and money in certain locations. They concluded that at least 70% of invasive species fund were used to just control the spread of unwanted plants in urban areas whereas rural areas did not spend nearly as much on invasive species control since it would be controversial (Gaetner *et al*., 2016).

More specifically, management techniques used to decrease invasive spread is the installation of portable vehicle wash units and appropriately located wash sites. A study showed that wash units that are used on vehicles for 5-6 minutes can remove 80% of the waste the vehicle transports, and if the vehicle is washed for 9 minutes it can remove 90% of waste that could potentially be transported (Rew *et al.*, 2018). Clearly washing your vehicle is a good solution for removing and restricting the spread of invasive seeds.

Another management technique could be various types of cutting treatments on roadside vegetation. A study done by Parr and Way (1998), illustrated the affects of eleven different cutting treatments within an 18-year period. The outcome presented cutting roadside verges lead to gaps in the soil allowing greater opportunity for invasive plant species to take advantage of the unoccupied soil. They also noticed that by leaving the cuttings on the roadside, it will reduce the survival of vegetation since the cuttings will block the sun from getting to the roots or seeds. Cuttings will also inhibit uncut vegetation from being able to establish their seeds in the ground after the end of their growing season.

2.0. MATERIALS AND METHODS

To accomplish this study, I followed the guidelines from a similar systematic review as prescribed by my supervisor. It took from November 2018 until April 2019 to gather enough research to present this review. The following methods below describe similar methodologies that were recommended from another similar literature review (Leverkus *et al.*, 2018).

2.1. LITERATURE SEARCH

The primary literature search was conducted in English through scholarly engine searches such as scholar's portal. The aim was to answer the main research question: Is there a predictable rate of spread in non-native invasive plant species throughout primary, secondary and tertiary road types and how can we reduce it? Key terms that appeared frequently in titles, abstracts and keywords sections was the motive for incorporating literature sources to this review. The literature search began in November 2018 to encompass data from all recent studies since 2000 that were published and peer reviewed. Within each search, initial restrictions were added to narrow down the types of literature that would appear. In this case, fields were restricted to environmental sciences, ecology, forestry, biodiversity and conservation of road networks as well as a downloadable full text of the study.

2.2. ARTICLE SCREENING

To successfully collect relevant information for this study, a series of 20 peer reviewed papers, journals and articles were compiled and sorted through based on their relevance to the thesis topic; facilitation of non-native invasive plant species along different road segments. To properly screen through all the relevant sources, restrictions were placed to further focus on these sources. Each source was given careful consideration in terms of data content and organized according to the conclusions derived from those studies. Sources selected are from recent studies, no older than 10 years.

2.3. STUDY QUALITY AND VALIDITY ASSESSMENT

Each piece of literature must have had an adequate amount of data that could be organized. This step ensurde that all data can be compiled into a database and displayed graphically. Once all data is entered into a database, the validity of compiled data was checked so that each set of data would give a proper representation of the vegetation population. Also, to ensure that the data from different sources can be properly weighed against one another, it was confirmed that all data was in the same units, organized properly by geographic regions and within the same test. This allowed statistical tests to be fluent, efficient and methodical.

It is also worth noting that most articles also collected data within 100 meters away from the road verge as a standardized method of sampling species.

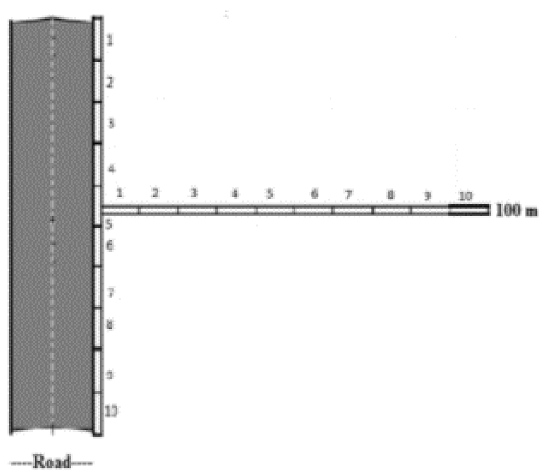

Figure 1. Standard sample area for studies (Dar *et al.*, 2015).

2.4. DATABASE STRATEGY OF ROAD SEGMENTS

After collecting the series of relevant literature, a database in excel was created where specific relevant data from each study is compiled and organized into groups. Tables and Figures where then created based on the data to accumulate some results. The hypothesis analysed species richness at each level of road, therefore, the figures and tables based on species richness were made. To understand and explain the results found, more descriptive data was extrapolated and addressed in the discussion section.

3.0. RESULTS

The data collected for this literature review derived from other peer-reviewed literature ranging from four continents around the globe. A total of twenty different articles address the biodiversity of invasive plant species along various road types within each of the article's specific study. Most of the data came from the United States in North America, the second highest source of information was from the United Kingdom in Europe, and little data came from Asian and Africa (Figure 2 and Table 1).

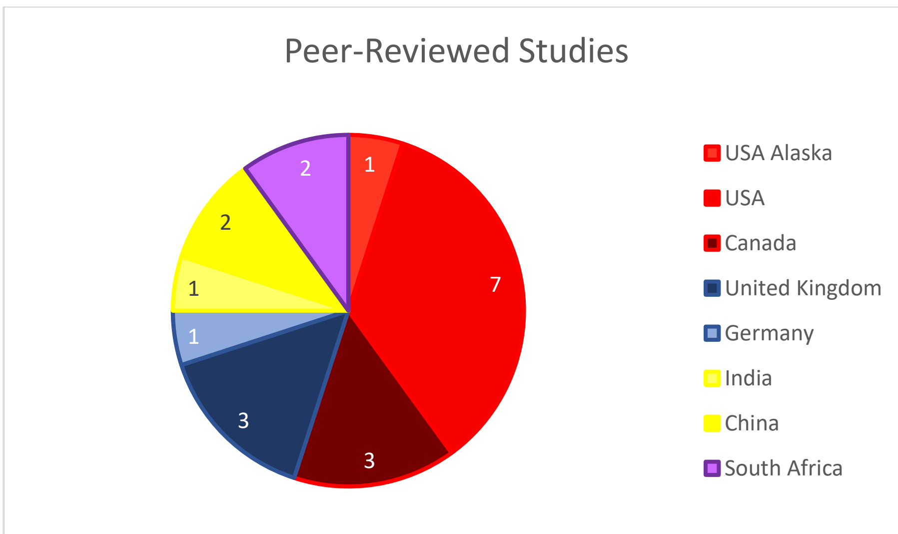

Figure 2. Distribution of studies referenced in this review. The red outline represents sources from North America, the blue outline represents sources from Europe, the yellow outline represents sources from Asia and the purple outline represents sources from South Africa. A total of 20 peer reviewed articles were sourced . Note that this chart represents the total number of sources used both within the literature review and the results section.

From this data, species richness was determined along each type of road segment; primary, secondary and tertiary. The data represents various types of invasive plant species on a global scale, meaning that all species organized in the data are not restricted by preferred climate conditions. The table shows that out of the four continents, invasive plant species are more likely to establish and facilitate tertiary roads and less likely to facilitate on primary roads. Seven of the datasets gathered were from North America, two data sources were gathered from Europe, two sets of data were gathered for Asia and two from Africa. In total, there was thirteen different datasets from different sources organized in these results.

Table 1. Species Richness within primary, secondary and tertiary roads for each country. Notice only 13 of the total 20 sources had applicable datasets which are used in figure 2.

Continent	Country	Primary	Secondary	Tertiary	Average No. of species for each continent	Source #
North America	USA Alaska	-	-	10	24	1
	USA	5	5	13	-	2
		-	-	69	-	3
		-	98	-	-	4
		-	-	3	-	5
	Canada	1	-	-	-	6
		15	-	-	-	7
Europe	United Kingdom	12	-	-	10	8
	Germany	7	12	-	-	9
Asia	India	-	-	186	108	10
	China	29	-	-	-	11
Africa	South Africa	20	-	-	43	12
		55	55	-	-	13
	Average # of species	18	42	56		

An average of 18 invasive species prefer primary roads, 42 invasive species prefer secondary roads and 56 invasive species prefer tertiary roads (Table 1). The table also shows that only 24 invasive plant species were studied in North America, 10 were studied in Europe, 108 were studied in Asia and 43 were studied in Africa. There were more studies done in North America but there were more species studied in Asia. The average species richness among the three road types is represented in figure 3 following an illustration of each in figure 4.

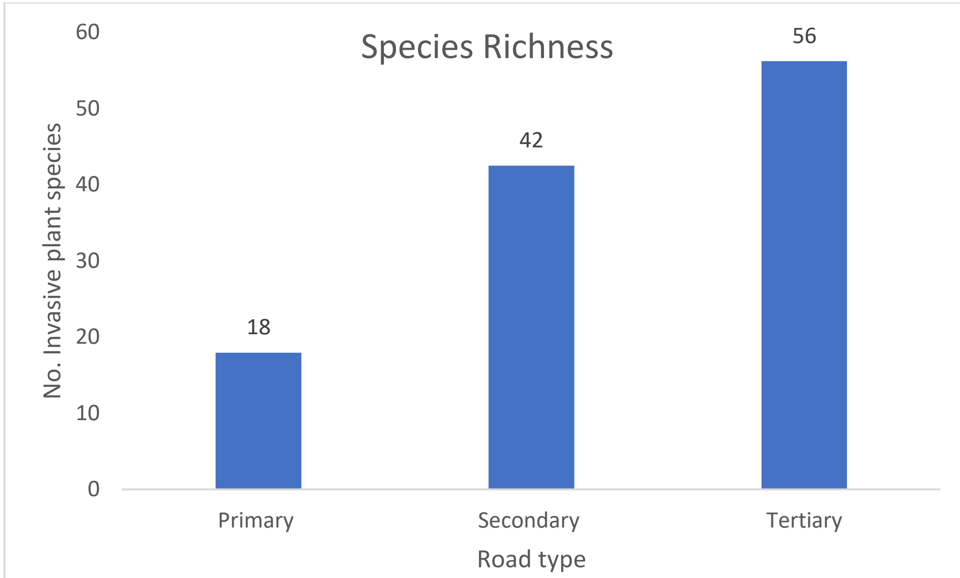

Figure 3. Average invasive plant species richness along primary secondary and tertiary roadside soil.

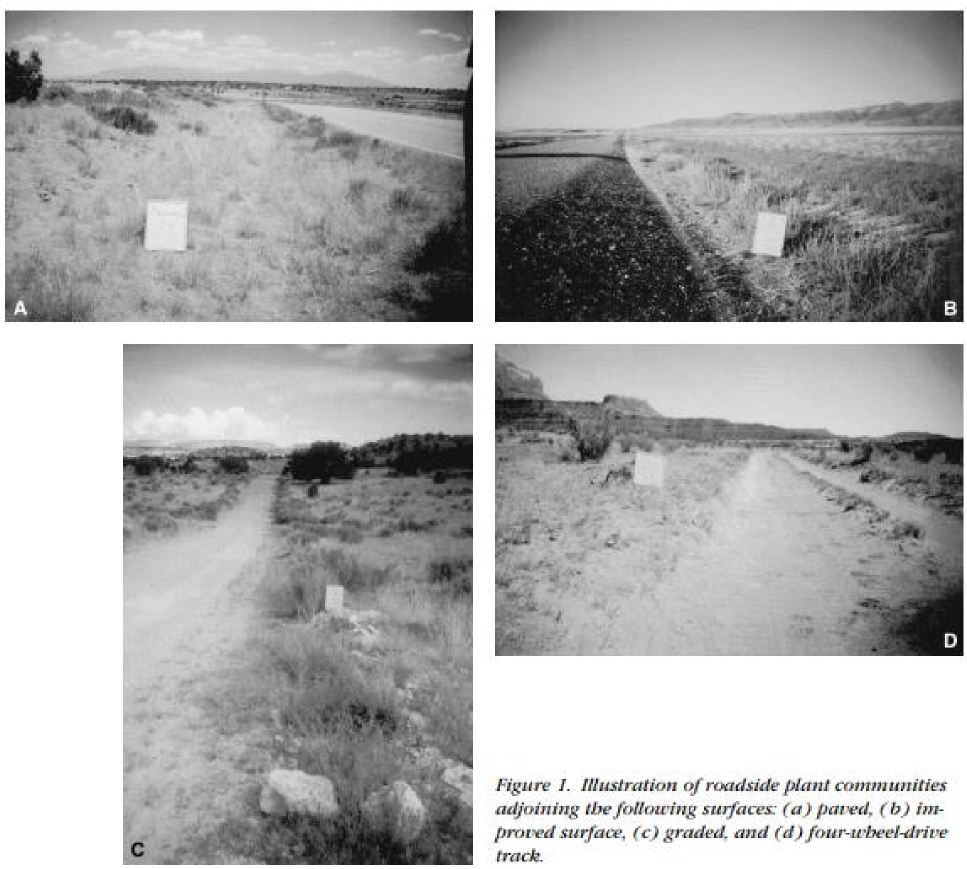

Figure 4. An illustration of roadside plant communities adjoining the following surfaces: (a) paved, (b) improved surfaces, (c) graded, and (d) four-wheel-drive track. (Gelbard and Belnap 2002).

4.0. DISCUSSION

My alternative hypothesis was based on the assumption that high vehicle density among primary road types would advance the spread of invasive plant species since seeds are likely to hitch a ride to further destinations much quicker. However, after analysing the data it is seen that tertiary roads facilitate the most spread. This means that both the null hypothesis and the alternate hypothesis were rejected. There are many reasons to explain this outcome, either by scientific evidence, or source of error.

4.1. ROADSIDE SOIL CONDITIONS

Roadside soil is most often composed of artificial substrates which restricts growth of most plant species. To make a primary road, a path is paved, and a curb is developed using coarse gravel substrates. This gravel roadside collects all toxins, salts and dust emitted and thrown from vehicles which becomes very undesirable for most plants. Of course, underdeveloped roads with low vehicle occupancy will have a smaller impact to the original ecological conditions and therefore, roadside soils will continue to be suitable habitats for plant species. This can explain the reduced number of invasive plant species on primary roads and more invasive plant species on tertiary roads.

Northern climates are more prone to salt impacts on vegetation since salt is commonly spread on roads to prevent icy conditions. This means that high concentrations of NaCl on primary roads are found in corresponding roadside soils, consequently resulting in high toxicity of Na^+ and Cl^- and more alkaline soils (soil pH levels of >8.5). This is significant since the majority of plants tolerate soil pH levels between 6.0 -7.0 which is an acidic to basic pH level (Gibbson *et al.*, 2017).

In southern climates where salt is generally not an issue, there is still toxicity on road segments which accumulates into nearby soils. This toxicity is likely from heavy metals emitted by vehicles, either from the vehicles exhaust or from the wear of vehicle parts. These metals are Pb, Cd, Zn, Cu and Ni, and since these metals do not naturally degrade over time their contribution to toxic environments will be significant (Ghosh *et al.*, 2009). Although it is noted that vegetation will use some heavy metals for plant metabolism like Cu, Mn and Zn, they can only handle them in trace amounts. High concentrations of unnecessary elements will cause chlorosis and necrosis for plants and since vehicles are more active on primary roads and highways, roadside soil along these corridors will be most susceptible to toxic environments.

Soils along tertiary roads are not significantly impacted by salt or heavy metals because vehicles in the area are scarce. There is no need to heavily salt infrequently used roads and heavy metals will not be as concentrated. This explains why there is a higher concentration of invasive species along tertiary roads. Invasive plants are able to exploit natural living environments and since tertiary roads are not significantly impacted by unnatural conditions, they tend to thrive along tertiary verges.

4.2. GEOGRAPHIC LOCATION

The geographic location from which each study was completed could explain the frequency and abundance of invasive species richness in an area. A species is only considered invasive if it was transported outside its natural range, and so it becomes obvious that isolated locations will have less invasive species to begin with. For example, the study done on a rural isolated landscape within New England town, compared the richness of invasive species from the rural area to an urban area. The study concluded that regardless of the road density and type, the farther away the town was from the study area, the abundance of invasion would be decreased.

4.2.1. CLIMATE

Plants, in general, prefer warm climatic zones to grow. The sun gives them energy to grow and the warmth keeps them from going dormant and prohibiting growth. Therefore, regions closer to the equator will generally have a greater species richness. When looking at Table 1 it is noticed that North America has the smallest species richness whereas Asia and Africa have the highest richness of species.

4.2.2. FIRE DISTURBANCE

Fire is a global factor that affects many regions over a geological time scale and can be used to explain plant diversity on a global scale. According to Pausas and Ribeiro (2016) who wrote an academic journal on this topic, concluded that regions with more fire will have more diversity (see Appendix 1). Countries listed in Table 1 with the highest frequency of fire disturbance, according to the figure in the appendix, is in the Eastern end of India. India is also listed to have the most diversity of most invasive species. This could be a result of fire frequency in the area. The country with the lowest frequency of fire listed in table 1 is the United Kingdom and Alaska, which correspondingly also have the lowest invasive species diversity according to Table 1. This shows that the frequency of fire can contribute to plant diversity, and since every region will have a different fire frequency each region will also have a different plant diversity.

Regardless of road type and density, these are the general patterns of invasive plant diversities and could explain their abundance and help with knowing where to focus restoration efforts on a global scale.

4.3. NATIVE REHABILITATION

The significance of this review is to understand the patterns of invasive plant species along roadways and determine where conservation practises should be focused. From the data gathered, it is understood that invasive species facilitate their growth mostly on tertiary roads. Therefore, to restore native plant species back to their natural range, efforts to minimize the impact of invasive species should be primarily concentrated on tertiary road verges.

4.3.1. MOWING FREQUENCY

Manual cutting treatments are a good way to remove invasive plant species. However, depending of the plant characteristic, different techniques should be applied. For instance, coarse woody plants decreased in species richness when cuttings are more frequent, whereas grass and mosses increase in species richness when cuttings are more frequent. Therefore, different mowing frequencies should be applied depending on the plants on site.

4.3.2. TIMING

The timing of which cut treatments are taken place is very important for controlling invasive plant species. The objective is to cut plants down before the germinate so that reproduction cannot take place. According to Parr and Way (1988),who did research on this topic, found that the specific timing was not important as long as plants were cut before germination. A general rule is that all cutting treatments should be done in either June or July, since that is when most plant species begin to germinate.

4.3.3. CUTTINGS

The same article also suggests that the cuttings from mowing should be left on site since a smothering effect will inhibit the regrowth of invasive plants, especially herbs. Removing the cuttings is beneficial to the plants since the soil will decrease the levels of extractible potassium while leaving nitrogen unaffected. Hand raking away the cuttings will also benefit plants since scarification effect will take place which creates gaps for new plants to take up (1988). Leaving cuttings on top of the soil will prevent light from reaching the plant making it difficult for the plant to grow in general.

4.3.4. WASHING STATIONS

It is known that seeds hitch a ride on vehicles to expand their range, especially along tertiary roads. Off-road vehicles are particularly prone to getting lots of mud and seeds stuck to their tires which is perfect for facilitating spread. To restrict this from happening, people need to be cautious of this risk and wash their vehicles before transmitting the seeds to other vulnerable sites. To encourage this behaviour, vehicle washing stations should be appropriately placed on off-road sites and near tertiary roads. This can also apply to mowing machines. After each use of any tool in contact with invasive plant species should be washed or even sanitized before going to a new location. This will prevent the spread of hitch-hiking seeds.

5.0. CONCLUSION

Roads are extremely beneficial to humans as well as plants for transportation purposes, but ecologically, roads are damaging to natural ecosystems. Roads not only fragment habitats but also facilitate the spread, increase the range and richness of invasive plant species. In this review, three main types of roads classified on a global scale are identified as primary, secondary and tertiary roads. Each of which represented a set of data that was unexpected from the hypothesis. The Research concluded that the spread and species richness of invasive plants along different types of road corridors has a distinguishable pattern that can be traced to properly incorporate management strategies. In this review it was found that invasive plant species have the highest species richness along tertiary roads and therefore tertiary roads need to be the focus of remediation tactics. Factors like soil quality, geographic locations, climate and fire disturbance all were discussed as to why this is the case. This topic is significant because it introduces the idea of effective conservation methods along roadways.

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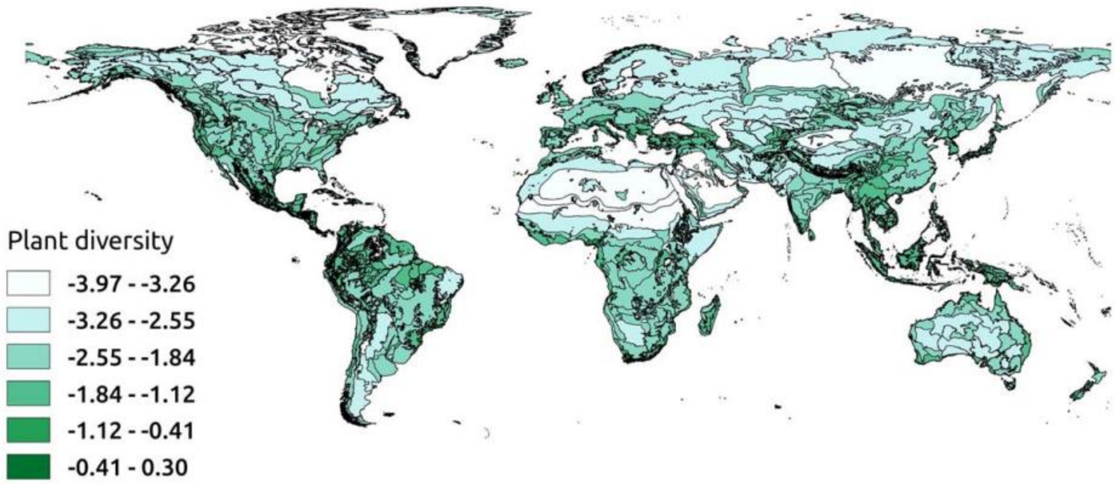
7.0. APPENDICES

a



b

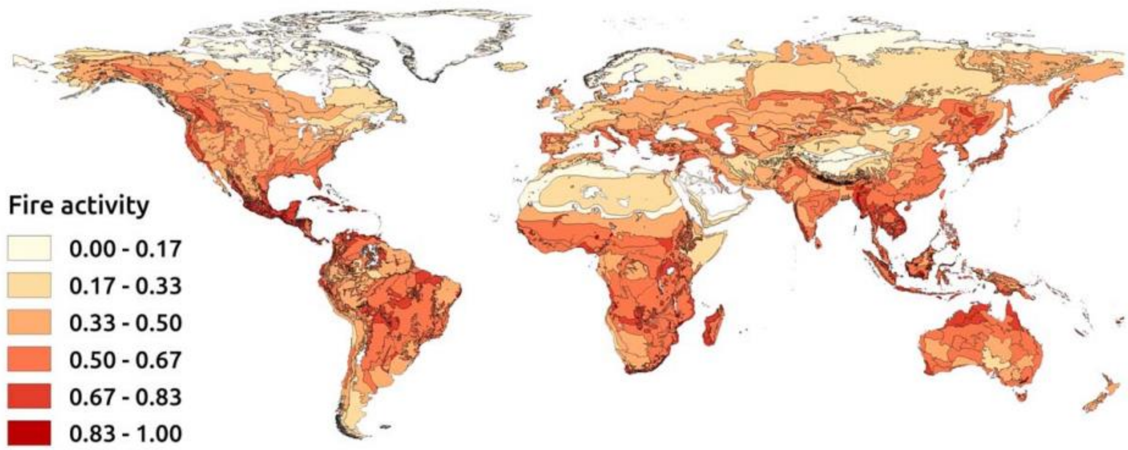


Figure 5. Plant diversity (a) versus fire activity (b) on a global scale. This is used to explain section 4.2.1.