Journal of Environmental Management 206 (2018) 547–555

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Hitching a ride: Seed accrual rates on different types of vehicles

Lisa J. Rew [a, *], Tyler J. Brummer [a], Fredric W. Pollnac [a], Christian D. Larson [a], Kimberley T. Taylor [a], Mark L. Taper [b], Joseph D. Fleming [c], Harold E. Balbach [d]

[a] Department of Land Resources and Environmental Sciences, Montana State University, Bozeman, MT, 59717, USA
[b] Department of Ecology, Montana State University, Bozeman, MT, 59717, USA
[c] USDA Forest Service, San Dimas, CA, 91773, USA
[d] US Army ERDC, Champaign, IL, 61826, USA

A R T I C L E I N F O

Article history:
Received 20 June 2017
Received in revised form
12 October 2017
Accepted 25 October 2017

Keywords:
Long distance seed dispersal
Seed attachment
Invasive species
Human-mediated dispersal
Road ecology
Vehicle washing

A B S T R A C T

Human activities, from resource extraction to recreation, are increasing global connectivity, especially to less-disturbed and previously inaccessible places. Such activities necessitate road networks and vehicles. Vehicles can transport reproductive plant propagules long distances, thereby increasing the risk of invasive plant species transport and dispersal. Subsequent invasions by less desirable species have significant implications for the future of threatened species and habitats. The goal of this study was to understand vehicle seed accrual by different vehicle types and under different driving conditions, and to evaluate different mitigation strategies. Using studies and experiments at four sites in the western USA we addressed three questions: How many seeds and species accumulate and are transported on vehicles? Does this differ with vehicle type, driving surface, surface conditions, and season? What is our ability to mitigate seed dispersal risk by cleaning vehicles? Our results demonstrated that vehicles accrue plant propagules, and driving surface, surface conditions, and season affect the rate of accrual: on- and off-trail summer seed accrual on all-terrain vehicles was 13 and 3508 seeds km^{-1}, respectively, and was higher in the fall than in the summer. Early season seed accrual on 4-wheel drive vehicles averaged 7 and 36 seeds km^{-1} on paved and unpaved roads respectively, under dry conditions. Furthermore, seed accrual on unpaved roads differed by vehicle type, with tracked vehicles accruing more than small and large 4-wheel drives; and small 4-wheel drives more than large. Rates were dramatically increased under wet surface conditions. Vehicles indiscriminately accrue a wide diversity of seeds (different life histories, forms and seed lengths); total richness, richness of annuals, biennials, forbs and shrubs, and seed length didn't differ among vehicle types, or additional seed bank samples. Our evaluation of portable vehicle wash units showed that approximately 80% of soil and seed was removed from dirty vehicles. This suggests that interception programs to reduce vehicular seed transportation risk are feasible and should be developed for areas of high conservation value, or where the spread of invasive species is of special concern.

1. Introduction

The role that humans play in the introduction and subsequent dispersal of native and non-native species has recently garnered attention (Arevalo et al., 2005; Pauchard et al., 2009; Seipel et al., 2012). Plant communities along transportation corridors can differ significantly from the composition of adjacent interior communities (Gelbard and Belnap, 2003; Tikka et al., 2001; Veldman and Putz, 2010). The effects of road maintenance (mowing, herbicide spraying, and grading of unpaved roads), combined with the abiotic effects of roads (altered substrate and hydrology), make roadsides unique ecosystems that can be more susceptible to the establishment of ruderal and non-native vegetation when compared with interior ecosystems (Coffin, 2007; Greenberg et al., 1997; Hansen and Clevenger, 2005; Hendrickson et al., 2005; Pickering and Mount, 2010; Rauschert et al., 2017; Veldman and Putz, 2010; Zwaenepoel et al., 2006).

* Corresponding author.
E-mail addresses: lrew@montana.edu (L.J. Rew), tyler.brummer@gmail.com (T.J. Brummer), fwpollnac@gmail.com (F.W. Pollnac), utah131@gmail.com (C.D. Larson), kimberleytaylor7@gmail.com (K.T. Taylor), mltaper@gmail.com (M.L. Taper), jdfleming@fs.fed.gov (J.D. Fleming), Hal.E.Balbach@usace.army.mil (H.E. Balbach).

https://doi.org/10.1016/j.jenvman.2017.10.060

In addition to disturbances that create conditions favorable for the establishment of undesirable plant species, transportation corridors and roadways can act as vectors for seed transport (Taylor et al., 2012; Veldman and Putz, 2010; Vakhlamova et al., 2016; von der Lippe and Kowarik, 2007). Studies have recorded the presence of seeds from a range of species on and in vehicles (Auffret and Cousins, 2013; Clifford, 1959; Hodkinson and Thompson, 1997; Lonsdale and Lane, 1994; Pickering and Mount, 2010; Schmidt, 1989; Veldman and Putz, 2010; Zwaenepoel et al., 2006). Using roadway tunnels to study seed transport by vehicles, von der Lippe and Kowarik (2007) found significant seed quantities in tunnels and concluded that long-distance transport of seeds by vehicles is the rule rather than the exception. Seed transport by vehicles is likely due to both the slip stream (airflow) around a vehicle as it moves (von der Lippe et al., 2013) and/or by physical attachment onto the vehicle's frame (Taylor et al., 2012).

Seed transport by vehicles is likely to disperse seeds farther than other anthropogenic modes such has hiking (Wichmann et al., 2009) or mountain biking (Weiss et al., 2016). Taylor et al. (2012) showed that >85% of seeds previously attached to a vehicle remained in place for several hundred kilometers under dry conditions on either paved or unpaved roads. In their roadway tunnel study, von der Lippe and Kowarik (2007) found that non-native seeds accounted for half of the number of species found and over half of the total number of seeds. Furthermore, Vakhlamova et al. (2016) found national roads, where vehicles likely travel longer distance and into new regions, have higher richness and percentage of non-native species than local roads. Roadways have been found to contribute to the spread of non-native species in many different systems: mountain landscapes (e.g. Arevalo et al., 2005; Pauchard et al., 2009; Seipel et al., 2012), semi-arid landscapes (Gelbard and Belnap, 2003), taiga (Hendrickson et al., 2005), temperate deciduous forests (Huebner, 2010), and tropical dry forests (Veldman and Putz, 2010). The construction of new roads, and maintenance of existing ones, coupled with the increased vehicular traffic (on- and off-road), presents a unique conservation challenge in terms of preventing and managing the spread of non-native and invasive plant species.

Despite the literature on seed dispersal by vehicles and differences in the vegetation alongside and adjacent to roadways, studies have not quantified the rate of seed accumulation by different vehicle types, under different driving conditions (i.e. wet or dry conditions), or along different surfaces (paved, unpaved and off-road). This information is necessary to determine the potential of vehicular traffic to act as seed dispersal vectors, and assess the risk of spread of plant species (Auffret and Cousins, 2013). Thus, the first goal of the study was to evaluate the rate of seed accrual onto vehicles under a range of different conditions. For this goal, our objectives were to evaluate the rate of seed accrual (1 or 100 km^{-1}), total seed abundance, and species richness on: 1) all-terrain vehicles driven on- or off-trail in two seasons; 2) four different vehicle types driven on different surfaces during early summer.

To address the potential for vehicles to act as seed dispersal vectors, the USA Forest Service currently commissions portable vehicle wash units (VWU) to clean vehicles at sites where wildfires are being actively managed, the military cleans vehicles between training activities, and there is interest in the use of portable wash units to treat vehicles entering sensitive areas. However, the effectiveness of current portable cleaning equipment has not been quantified and there are few established guidelines by government agencies. To address this need, the second goal of our study was to quantify the effectiveness of different portable vehicle wash units (VWU) at removing plant propagules and soil from different types of vehicles. The objectives for this second goal were: 1) evaluate the efficacy of five different VWUs to remove soil waste from different vehicle types, 2) determine the efficacy of the VWU washing protocol (cleaning, filtering, and containment) on the survival of different seed types, 3) quantify the efficacy of the primary VWU over different wash durations.

2. Methods

2.1. Seed accrual studies

Seed accrual was assessed in two ways: (1) using all-terrain vehicles (ATV) driven on- and off-trail in summer and fall; (2) using four vehicle types driven primarily on unpaved roads during early summer.

2.1.1. All-terrain vehicles driven on- or off-trail

Seed accrual onto recreational ATVs was assessed during the summer (July) and the fall (September) of 2008, in Montana, USA. All-terrain vehicles were driven a fixed distance (3.2 km) on two different courses, with different surfaces (on-trail and off-trail). Both courses ran through mixed sagebrush and open conifer habitat. The on-trail course was conducted on a 2.5 m wide unpaved former logging road (45° 26′ 13″ N, 111° 10′ 09″ S) and the off-trail course was nearby (45° 26′ 19″ N, 111° 14′ 03″ S). After travelling the set distance the ATVs were washed. Due to the VWU's filtering (200 microns) and containment procedures taking hours to complete, washes from multiple vehicle runs of the same type were collated for each replicate. There were three replicates on each of the two courses/surfaces, in each season. Before starting each replicate, the ATV was cleaned using the VWU. Following this pre-wash, the ATV drove a lap around the course, after which it washed and the seeds and soil it accrued during the lap were captured and contained by the VWU. This iteration occurred 24 times per replicate (total of 76.8 km). The vegetation was tall (~1 m) at the off-trail site, causing some seed to accumulate on the vehicle (e.g. on top of wheel fairings). These seeds were removed and bagged prior to washing, and the seed biomass weight was recorded by species. Germinable seed numbers were assessed by germinating them in the same manner as the vehicular seed and soil waste samples (see below). This provided consistent estimates between the different seed collection methods.

Once a replicate was completed, the soil and seed waste from the vehicles was contained and transported back to the Montana State University (MSU) Plant Growth Center, where it was mixed with pasteurized soil to provide a consistent medium, placed in seed trays, and monitored for growth. (In previous experiments, seedling survival of the pasteurization process and subsequent contamination of greenhouse experiments has been non-existent, thus we did not have control trays.) Seedling establishment from our trays was monitored and recorded for 20 months. Seedlings were removed from trays after they had been identified to the species level and the soil was subsequently disturbed to facilitate further germination. To address possible seed vernalization requirements, after 9 months and when new establishment had ceased, the trays were moved to a cold, dark room (4 °C) for 8 weeks. After the 8 weeks, the trays were returned to the greenhouse and new seedling emergence was monitored for another 9 months. Plants were grown under a 16-h photoperiod of natural sunlight supplemented with mercury vapor lamps (165 μE m−2 s−1) at 22 °C (day), with 15 °C at night. Plants were watered as needed throughout. A few plant specimens were grown to maturity for identification purposes, these were placed in separate pots and a different greenhouse, with the same climate conditions, to prevent any seed contamination of the seed trays. The process from containing the soil and seed waste in the field, through to recording individual species' abundance, is hereafter referred to as the VWU