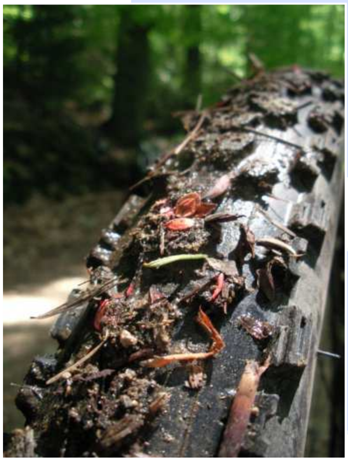
UNIVERSITY OF FREIBURG

Faculty of Environment and Natural Resources
Department of Nature Conservation and Landscape Ecology

Testing the potential of mountain bikes as seed dispersers

Bachelor thesis

[redacted]



First examiner:
Dr. Gesine Pufal

Second examiner:
Prof. Dr. Michael Scherer-Lorenzen

Freiburg, 30.09.2014

Acknowledgements

There are some people who helped me during my work on this thesis and made this research possible. I especially thank Dr. Gesine Pufal for her ideas, valuable advice and dependable support as supervisor of this thesis. The department of Nature Conservation and Landscape Ecology and the department of Biometry of the Albert Ludwigs-University provided important material for the fieldwork. I also would like to thank Tyler Brummer of the Lincoln University, New Zealand for his valuable help with the data analysis. For their supporting interest in my work, I especially thank Joachim and Bernd. Last but not least, I want to thank Leni and Martin for their patient help, encouragement and entertainment during the field work and the whole process of writing this thesis!

Table of contents

1. Introduction

Plants are immobile; to reach and colonize new habitats their seeds need to be transported away from the parental plant. The dispersal of propagules (seeds, spores, whole individuals, plant parts) is crucial to the demographic and genetic distribution of individuals within a population, a habitat or a region. Seed dispersal is therefore a key-factor for understanding population dynamics. Propagule pressure can be essential when it comes to establishment in a new habitat (Pauchard & Alaback, 2004). Successful seed dispersal also allows seeds to germinate in some distance from the parental plant and thus prevents competition within the own species.

Some species are capable of actively dispersing their seeds (*Autochory*). Others rely on vectors to facilitate dispersal (*Allochory*). Determining the consequences of dispersal requires identifying and understanding these vectors. In general the process of passive dispersal can be divided in departure, transfer and settlement. Passive seed dispersal has been categorized into *Anemochory* (dispersal by wind), *Hydrochory* (dispersal by water), *Zoochory* (dispersal by animals) and *Anthrochory* (dispersal by humans). The morphological dispersal syndrome (MDS) names the fact that many plant species specialize on one or more mechanisms which they rely on in terms of seed dispersal (Higgins et al., 2003). Usually the plant and its propagules are physically and ecologically adapted to these specific mechanisms. Most natural mechanisms involve seed dispersal within only a few meters distance from the parental plant (Nathan et al., 2008; Wichmann et al., 2009)

Mankind is constantly shaping its environment. In many places mankind's growing influence on ecosystems results in the change of certain habitat properties, the loss of biodiversity or even the permanent loss of habitats. One specific effect of human intervention can be a permanent change in species composition. Generally there are two major ways in which humans influence the distribution of species. The first one is the alteration by human land use. The second one is the change of dispersal patterns through human movement of whole individuals, seeds or other plant parts. Dispersal by humans was formally considered as *Zoochory*, but research found that humans differ from animals in their function of seed dispersal. Dispersal by humans is therefore referred to as *Anthrochory.* Recent research (Wichmann et al., 2009) showed that human vectors have a much higher mobility than animal vectors, caused by technical means of human transportation. The influence of human-mediated dispersal (HMD) reaches from a local scale up to bio-geographical dimensions. Many species, such as *Ambrosia artemisiifolia* (Brandes & Nitzsche, 2007), have spread globally through the aid of humans. In many regions native or endemic species are being displaced by invasive species, which were originally spread by humans. Trans-location of species by humans poses one of the most severe threats to biodiversity world wide (Riccardi, 2007) and reached a high status in research agendas (Millenium Ecosystem Assessment, 2005). Human-aided dispersal of plant seeds either happens intentional or unintentional. On different occasions humans willingly introduced certain plant species to shape their environment after their needs. For example non-native plant species were used for soil conservation work and rehabilitate eroded land (Johnston & Pickering, 2001) or other species were introduced to cover ski slopes in the off-season (Johnston & Pickering, 2001; McDougall et al., 2005). But while the intentional ways of HMD are known and therefore more easily influence-able, the unintentional ways are harder to predict, in part also due to their lack of prominence. The unintentional dispersal of plant seeds by humans is likely to be highly relevant in ecological therms, but the mechanisms of HMD tend to be complex and the importance of many potential vectors is still indistinct. While the processes following the introduction leading to establishment and possible invasions are rather well researched by now, pathways of dispersal and initial introduction yet lack research (Lee & Chown, 2007). This knowledge gap is crucial for nature conservation (Lonsdale, 1999) and can impede effective management (Lee & Chown, 2009) because seed dispersal has been recognized as one of the main factors controlling plant invasions (Veldman & Putz, 2010). Humans are often unaware of their role as seed vectors. They can facilitate intra-regional homogenization of native species but also support the spread of non-native species (Lee & Chown, 2007). Alien species may change ecosystem functions, alter hydrology, influence regional fire regimes, change species composition and degrade overall biodiversity as well as directly replace native species (Asner & Vitousek, 2005; Mack et al., 2000; Pickering et al., 2011a). Hence, they have become a growing concern to protected areas (Pauchard & Alaback, 2004).

One aspect contributing to the relevance of HMD is the dispersal over exceptional long distances. Most natural dispersal mechanisms usually disperse seed not more than a few meters (Willson, 1993; Nathan et al., 2008), the distance of dispersal via HMD however, is likely to be greater (Pickering et al., 2011a). The morphological dispersal syndrome (MDS) is assumed to be responsible for the majority of dispersal events (Higgins et al., 2003). Consequently, MDS are considered to be the standard vectors of dispersal for the plant seeds. However, while it was observed that the MDS concept describes local dispersal processes quite well (Hughes et al., 1994), long-distance dispersal (LDD) is assumed to be dominated by vectors other than MDS, thus non-standard dispersal vectors (Higgins et al., 2003). Often LDD is a result of repeated dispersal by multiple vectors (Higgins et al., 2003). Although the minority of dispersal events are LDD events, they play a disproportionate role in plant ecology and influence large scale processes, for example defining rates of migration (Higgins et al., 2003; Nathan et al., 2008). Already small amounts of seeds can induce the establishment of a new species (Gaston et al., 2003; Lee & Chown, 2007). Therefore, LDD of plant seeds is extremely important when considering plant invasions. Multiple studies have shown that HMD is able to lead to long-distance dispersal events (Wichmann et al., 2009; Pickering & Mount, 2010; Pickering et al., 2011a).

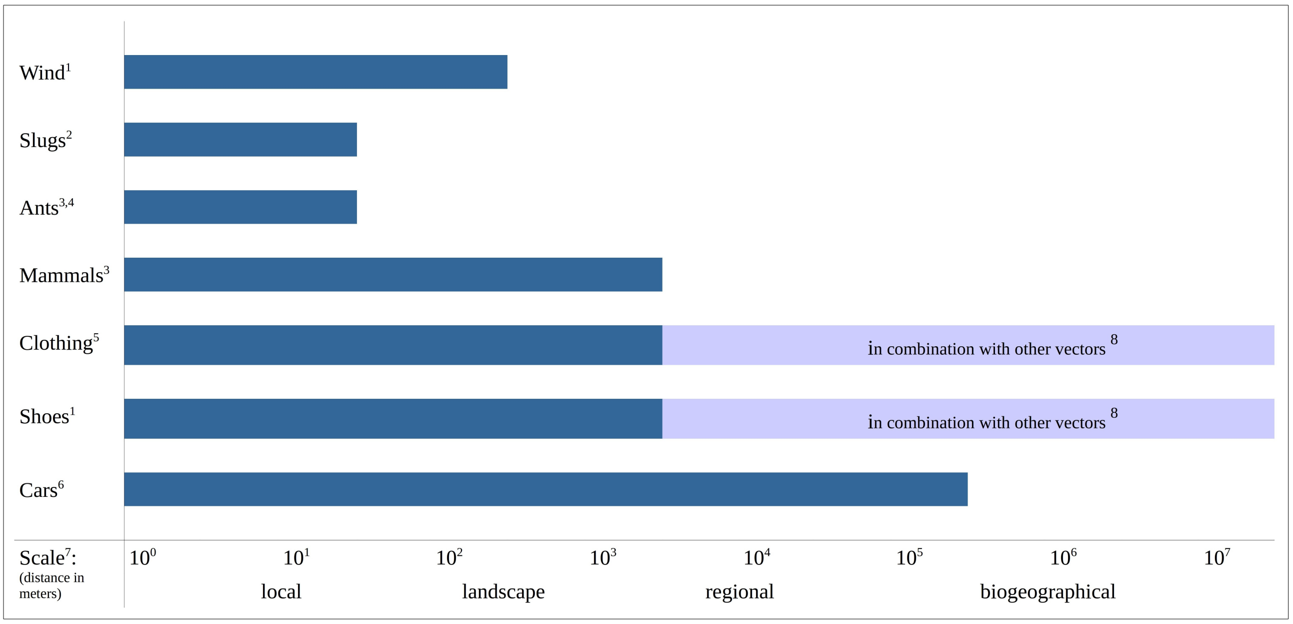


Figure 1.1. *Maximum distances of passive dispersal by different vectors. (1) Wichmann et al., 2009; (2) Tuerke et al. (2010); (3) Gomez & Espadaler, 1998; (4) Davidson & Morton, 1981; (5) Bullock & Primack, 1977; (6) Taylor et al., 2012; (7) Nathan et al., 2008; (8) Lee & Chown, 2009.*

Unintentional HMD plays an important role in recreational and nature-based activities, of which several have been identified as important pathways of seed dispersal (Pickering & Mount, 2010). In natural ecosystems, where often-times other human activities are not permitted, nature-based tourism and recreational activities could act as the main dispersal mechanisms for new species (Worboys et al., 2005; Pickering & Mount, 2010). In many protected areas nature-based tourism intentionally promoted (Pickering et al., 2010b). Therefore, unintentional HMD might play a major role in facilitating plant invasions in protected areas (Pickering et al., 2011a). In many protected areas it was already observed that tourist activity is associated with the presence of non-native species (Lonsdale, 1999). Multiple studies identified human clothing as a way of transport for plant seeds (Mount & Pickering, 2009; Pickering & Mount, 2010; Pickering et al., 2011a; Lee & Chown, 2009). One study remarks that hiking boots are able to transport seeds up to 5000m (Wichmann et al., 2009). In Australia there were seeds of 179 species found on shoes, socks and trousers of hikers during several studies (Mount & Pickering, 2009). Also cars were verified as a potential dispersal vector (Wace, 1977; Schmidt, 1989; Lonsdale & Lane, 1994; Zwaenepoel et al., 2006; Lippe & Kowarik, 2007). Moreover, horses and donkeys as means of transportation were subjects of research. Seeds were discovered in the fur (Couveur et al., 2004) and in dung (Campbell & Gibson, 2001; Gower, 2008). Despite its recognized importance, there is a gap in research on relative rates of HMD (Pickering & Mount, 2010; Pickering et al., 2011a) and more studies about HMD and its vectors are needed (Pickering & Hill, 2007; Wichmann et al., 2009; Pickering et al., 2010b), especially because recreational activities are increasingly gaining popularity all over the world and there has been a massive growth of nature-based tourism in the past decades (Turton, 2005; Worboys et al., 2005; Schraml et al., 2014).

There have been several publications, which ponder the potential of mountain bikes acting as seed dispersers (Karger, 1997; Turton et al., 2000; Day & Turton, 2000; Turton, 2005; Smith & Turton, 1995; Wilson et al., 2004; Pickering & Mount, 2010; Pickering et al., 2010a; Pickering et al., 2010b). But so far, there is no research quantifying the seed-dispersal by mountain bikes, although mountain bikes clearly have the potential to act as seed vector (Pickering & Mount, 2010). Studies concerning the environmental impacts of mountain bikes mostly focus on more direct effects like soil erosion, vegetation damage and trail degradation (Pickering et al., 2010b). Overall there is still limited research about the environmental impacts of mountain biking compared to other recreational activities such as hiking and horse riding (Pickering & Hill, 2007; Newsome & Davis, 2009; Pickering & Mount, 2010; Pickering et al., 2010a; Pickering et al., 2010b).

However, certain factors make mountain biking an especially promising research topic in the field of unintentional HMD. Mountain biking arose as new recreational activity almost 30 years ago (Webber, 2007). Since than, similar to other outdoor-activities (Worboys et al., 2005), it has been a globally growing sport (Day & Turton, 2000). Mountain biking is increasingly popular in Europe (Arnberger, 2006; Cordell, 2008), New Zealand (Mason & Lebermann, 2000), Australia (Hales & Kiewa, 2007; Newsome & Davis, 2009), and North America (Morey et al., 2002). In the United States 43.3 Million people rode a mountain bike in 2000 (NSRE, 2000), a number that is likely to have increased by today as the sport of mountain biking continues to grow (Hales & Kiewa, 2007). Several studies found that people who practice mountain biking tend to be significantly younger than those who participate in most other outdoor activities, for example hiking (Cessford, 2003; Schraml et al., 2014). This indicates the future potential of the sport. Popularity is also driven by a rapid development of equipment and bicycle technology which allows riding in harsher weather conditions and often year-round (Schraml, 2008). All over the world, trail networks, which were traditionally only used by walkers, are now being used by a progressing number of mountain bikers, too (Cessford, 2003). The result is a growing pressure of use that is applied in the popular riding areas. This is especially relevant for regions close to urban areas (Webber, 2007; Newsome & Davis, 2009), but trails in protected areas are also increasingly used for mountain biking (Marion & Wimpey, 2007; Newsome & Davis, 2009; Pickering et al., 2010b).

While walkers and cars have already been identified and studied as seed-dispersing agents, mountain biking has been considered, but its potential has never been quantified. However, the movement patterns of mountain bikers are very different from walkers and cars. Cars on the one hand have a relatively large range of influence and travel with relatively high speed. Therefore they also significantly contribute to long-distance dispersal (Schmidt, 1989; Taylor et al., 2012) but they are bound to a certain infrastructure. On the other hand, walkers and hikers have a very high degree of area-permeation since they do not necessarily depend on a specific infrastructure but lack the high range of vehicles. Mountain biking combines both, the relatively high range and the high degree of area-permeation.

Cars are known to transport seed (Wace, 1977; Schmidt, 1989; Lonsdale & Lane, 1994; Lippe & Kowarik, 2007; Lippe & Kowarik, 2008) and several studies point out the exceeding abundance of exotics, environmental weeds and invasives along roads used by cars (Pauchard & Alaback, 2004; Arevalo et al., 2005; Becker et al., 2005; Pickering & Hill, 2007; Christen & Mattlack, 2008). This abundance is either caused by a vector (cars) or can also occur because of habitat-properties of linear road verges (Kowarik & Lippe, 2008). In many cases disturbances caused by road building and maintenance create favourable growing conditions for environmental weeds and invasives along car infrastructure (Spellerberg, 1998, Johnston & Johnston, 2004). Pauchard and Allaback (2004) and Spellerberg (1998) both suggest that the initial introduction of non-native species often happens via roads. So they are usually the first landscape elements to be colonized. Road habitats also act as a reservoir of different alien species (Parendes & Jones, 2000) and are often starting point for further dispersal (Kowarik & Lippe, 2008). Mountain bikers often access riding areas via roads and streets that are also used by cars. Therefore they could act as a connecting vector between car infrastructure and natural habitats which are not accessible by car.

As already stated, tourist infrastructure is frequently associated with non-native species. This is particularly the case for junctions such as train stations, tourist establishments or parking lots (Becker et al., 2005). Tourist infrastructure acts as a harbour for a diversity of intentionally or unintentionally introduced species (Kelly et al., 2003; Pauchard & Alaback, 2004; Pickering et al., 2007). Therefore, areas with high human activity serve as sources for invasions towards more pristine areas (Parendes & Jones, 2000). From there tourists may unintentionally transport seeds further into the ecosystem (Pickering & Mount, 2010). Mountain bikers also use tourist infrastructure as starting or access point for their rides. Again mountain bikers could pose as connecting vector and link species composition of highly developed tourist infrastructure and more remote habitats.

During their survey among mountain bikers in 1995 Morey et al. (2002) remarked that riders with suspension systems on their mountain bikes tended to prefer single trails and challenging terrain more than those without. During that time only the minority of mountain bikes (~40%) was equipped with suspension (Morey et al., 2002). Today almost all mountain bikes have suspension systems and deflexion of the suspension systems greatly increased. This technical development has made more terrain accessible for mountain bikers (Newsome & Davis, 2009). Aided by technical progress new riding styles of mountain biking like All Mountain, Enduro, Freeride, Downhill or Dirt emerged and led to an expansion of the sport to technically more challenging and remote terrain. Many riders prefer narrower and more natural trails (Morey et al., 2002) and more and more are using trails that were previously only accessible for walkers (Hollenhorst et al., 1995; Cessford, 2003). Also the sport has become more attractive and safer for a larger variety of people with different skill levels. With the rising number of people participating in the sport the phenomenon of crowding becomes a problem (Schraml et al., 2014). Many feel disturbed in the nature experience when encountering others and try to avoid them. The combination of the ability to access difficult terrain, the urge to discover something new and the attempt to avoid others results in the construction of new trails. In most cases these are not authorized (Pickering et al., 2010a) and often the managing authorities are not aware of these so called Social Trails. A relatively small number of riders is sufficient to create a social trail as 25 passes of a mountain bike already reduce vegetation cover significantly (Pickering et al., 2011b). Mountain bikers seem to have a particularly high tendency to create and use undesignated trails. During their study in the Queensland World Heritage Area Day & Turton (2000) found out that Social Trails made up 50% of the overall length of the trail network used by mountain bikers, whereas this number was only 20% for hikers (Butler, 2003). By now the topic has reached the broad public. In Germany the issue of unauthorized trail construction by mountain bikers has recently come into scrutiny of local media (e.g. Schwarzwälder Bote, 2014; Badische Zeitung, 2014; Göttinger Tageblatt, 2014). Mountain biking can be characterized as a backcountry-activity that is able to be carried out independently from managed infrastructure (Pickering & Hill, 2007). This makes mountain biking less predictable and harder to control than other recreational activities (Turton, 2005). Especially in sensitive ecosystems unplanned trail proliferation can cause diverse environmental issues. HMD may be one of them, as the more adventurous tourists are important seed vectors (Lonsdale & Lane, 1994).

Since 'discovering of something new' and 'searching for new challenges' are among the most important motivations for mountain bikers (Schraml et al., 2014), mountain biking has also developed to an international sport and into a form of tourism. Mountain bikers enjoy certain amounts of climbing and downhill passages (Morey et al., 2002), especially since technically development created many new opportunities. Mountain biking therefore particularly affects mountainous regions. At the same time, the majority of protected areas worldwide are located in mountainous regions (Scott et al., 2001). Many regions and protected areas promote mountain biking to attract more visitors and the use of mountainous areas for tourism is growing (Price, 2006). In the past mountainous areas were seen as being least vulnerable to invasions (Humphries et al., 1991). But this could already be changing. Mountainous ecosystems are very sensitive and the general resistance to invasions was the result of harsh climate, lack of adapted non-native species and low human activity (Pauchard et al., 2009). With climate change and additional human activity, mountainous regions will be more prone to invasions (McDougall et al., 2005; Becker et al., 2005; Pauchard et al., 2009). Also, simply high propagule pressure is said to have a compensating effect and cause aliens to establish despite harsh climate conditions (Pauchard & Alaback, 2004). It seems that already most invasive species in the Alps have been unintentionally introduced by humans (McDougall et al., 2005). Additional human activity such as hiking and mountain biking could further aid alien species to find suitable habitats (Becker et al., 2005).

Mountain biking could aid plant invasions because propagule pressure is one of the main factors for introducing non-native species to a new habitat (Lee & Chown, 2009). As potential vector of HMD it could contribute to altering propagule movement. Research on this topic is overdue, not at least because of the increasing popularity of the sport. An attempt to quantify seed attachment and detachment could be a first step to clarify mountain bikers' role as vectors of plant seeds.

With this thesis I plan to quantify seed attachment to and detachment from mountain bikes and therefore assess the potential of mountain biking as a vector for seed dispersal. For this purpose I will conduct a manipulative experiment in a natural environment measuring seed attachment and detachment under different conditions and discuss the results referring to mountain biking's role in HMD. The specific aims of this thesis will be:

a) To measure seed attachment and detachment over different distances to assess the quantity of seeds transported and maximum distances.

b) To determine how different seed properties influence the seed's tendency to attach and detach.

c) To identify the influence of different weather conditions on seed attachment and detachment.

d) To identify the effect of two different tyre models.

e) To assess certain rider habits and discuss their effect on the potential of mountain biking as a vector of HMD.

f) To integrate the findings in the current state of research concerning HMD.

2. Methods

2.1. Study area

The experimental component of my study took place in the southern Blackforest in the periphery of Freiburg i. Br. between June and August 2014. Mountain biking is a popular sport in this area of Germany. A recent study, which monitored visitors at ten representative locations in the Blackforest, found that of 6272 recorded visitors, 2053 (32.7%) were riding a mountain bike (Schraml 2014). At one location there were even more mountain bikers than people on foot. There is highly developed infrastructure consisting of forest roads and maintained and mapped hiking trails, both of which are frequently used for mountain biking. Trails are increasingly present in the mountainous and forest areas in the periphery of Freiburg.

For the experiment I chose a forest trail within the city limits of Freiburg (47°59'01.9"N 7°52'03.7"E, Figure 2.1.). The trail is located on the lower parts of the northern flank of the Kybfelsen (820m). The trail leads through managed forest and the vegetation mainly consists of Beech (*Fagus sylvatica*), Douglas fir (*Pseudotsuga menziesii*), Spruce (*Picea abies*), Fir (*Abies alba*) and Scots pine (*Pinus sylvatica*). The trail was slightly sloped and held a mix of different surfaces common for trails in the area. It featured hardpack, partly lose soil, coniferous litter, broad-leaf litter, small amounts of gravel and stony passages.

Figure 2.1. *A passage of the test trail*

2.2. Experimental design

I designed a manipulative experiment in a natural environment to determine the potential of seed-dispersal by mountain bikes. Similar to Wichmann et al. (2009), who studied the seed dispersal by hiking boots of walkers, I exposed the potential vector, the mountain bike, to seeds and measured initial attachment and remaining seeds after fixed distances. Seeds were deployed on the ground in a defined area (pick-up area). The mountain bike was than ridden through the pick-up area. After traversing it, the bike continued for a certain distance. Once this distance was completed the remaining seeds on tyres and frame were recorded. The distances were 0m, 5m, 10m, 20m, 50m, 100m, 200m and 500m for semi-wet conditions (see 2.4.) and 0m, 5m, 10m, 20m, 50m and 100m for wet conditions. There were ten runs carried out for each distance and for both weather conditions. The bicycle was ridden with a speed between 10 km/h (~6.2 mph) and 15 km/h (~9.3 mph) representing average uphill speed (personal experience). The pick-up area had the size of 213cm by 50 cm; 213 cm long to allow each wheel a full rotation within the pick-up area to reach maximum exposure of the tyres, 50 cm to ensure that the rider entirely hits the pick-up area with both wheels, even when crossing it not completely straight. 12500 seeds of five species were evenly distributed in the pick up area. The seed density per species was ~0.23 seeds · cm^{-2}, yielding a total seed density of ~1.17 seeds · cm^{-2}.

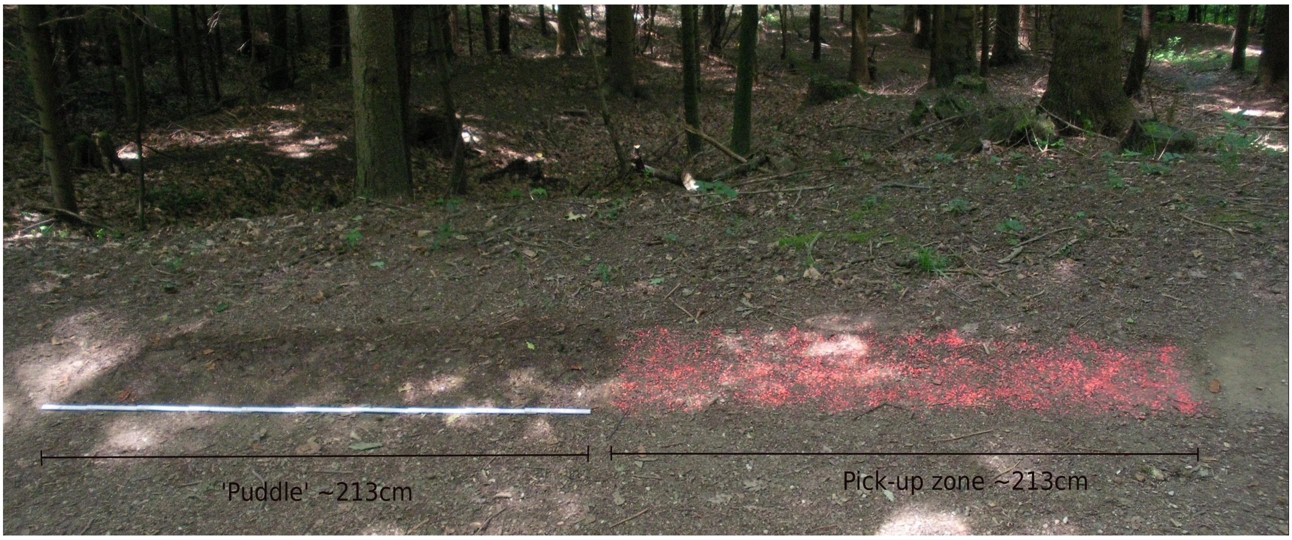


Figure 2.2. *The experimental set-up, including the Pick-up area and the 'puddle' added for the semi -wet conditions.*

I recorded the initial attachment of all five seed species in both weather conditions. Therefore seeds on the bike were counted at the distance of 0m, directly after traversing the pick-up area. To keep the number of seeds available for attachment constant for the following runs, the mean of the recorded initial attachment was added to the seeds deployed in the pick-up area after every run. The whole set-up was moved between different sections of the trail to ensure that for none of the distances the ten runs would be carried out in the same section of the trail. This was done to minimize a biasing influence of small differences in terrain.

The bike used for my experiment was a 2012 Bergamont Contrail LTD full suspension mountain bike. It featured a 120mm front- and rear-suspension. The Bicycle was running 26 inch wheels equipped with 2.25 inch (wide) tyres. During all the testing, both tyres were run with an air-pressure between 22 psi (~1,5 bar) and 26 psi (~1,8 bar). Therefore, the contact area of both tyres during riding was 45mm wide. One full rotation (development) of a 26 inch wheel with the mentioned tyres mounted is 213 cm. The weight of the described set-up was approximately 13kg (~28,7 lb).

The rider who rode the bicycle during the testing weighed 63kg (~138,9 lb) with clothing.

2.3. Seeds

I used seeds of five different species for the experiment. The species selection was made with the following criteria in mind. To prevent a negative influence of accidental dispersal, I did not use seeds of species that are considered invasive in the region in which the experiments were carried out. Multiple studies in the past have demonstrated that seed traits influence attachment- and detachment-rates (Bullock & Primack, 1977, Lee & Chown, 2009, Wichmann et al., 2009, Pickering et al., 2011a). Factors like size, weight, shape or surface area can have great effect on how far the seeds are dispersed and thus how fast a certain species could invade a habitat (Pickering et al., 2011a). So the species were chosen after the physical traits of their seeds. The effect of the seed traits can be valid for different species regardless of their origin or abundance. The aim was to gain results that are globally relevant, since there are regions where plant invasions are a much bigger concern than in the study area, the Blackforest. Additionally seed availability was also a factor influencing the choice of species. The following five species were chosen for the experiment: *Pastinaca sativa*, *Onobrychis viciifolia*, *Vicia villosa*, *Sinapis alba*, *Anthriscus sylvestris*, which I will refer to by their generic names in this thesis. The seeds of *Anthriscus* are elongate and slim. *Pastinaca* seeds are relatively large and flat (<1mm). *Sinapis* and *Vicia* represent spherical seeds, while *Vicia* are larger than *Sinapis*. The shape of *Onobrychis* can be described as roughly rounded with an uneven surface. An impression of shapes and proportions of the different seed species can be gained from Figure 2.3..

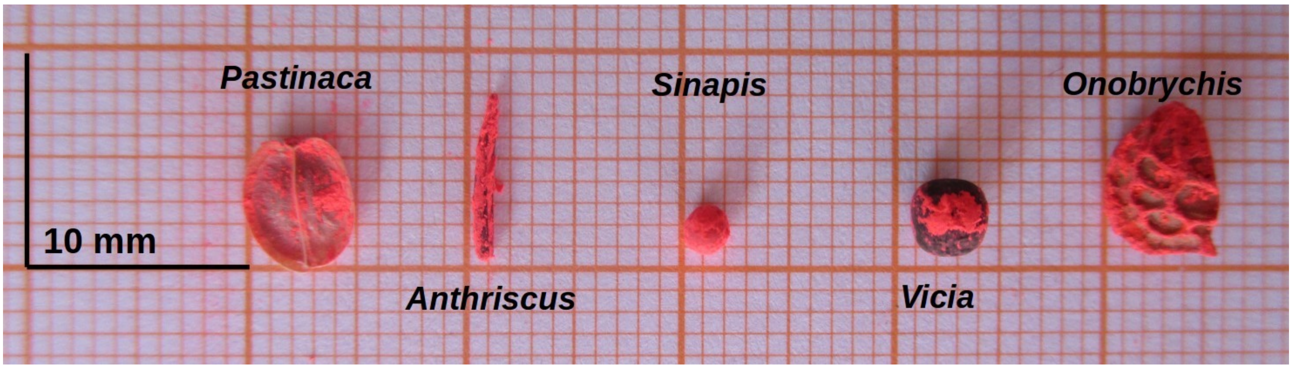


Figure 2.3. *Thickness: Onobrychis(<4mm), Pastinaca(<1mm), Sinapis(<3mm), Vicia(<4mm), Anthriscus(<2mm).*

The weight of the seeds represents another very important seed trait. I chose species with the aim to have a representative range of seed weights. The weights were determined by weighing 100 seeds of a species and calculating the average for a single seed (Table 2.1., scale: Steinberg SBS-LW-300A).

	Onobrychis	*Pastinaca*	*Sinapis*	*Vicia*	*Anthriscus*
Weight of one seed	20.6 mg	4.7 mg	6.3 mg	35.7 mg	2.8 mg

Table 2.1.

I used daylight UV-active bright pink pigment to colour-mark the seeds (Figure 2.3.). For all species except *Pastinaca* I additionally used Paraloid B72 (15% solution in Ethylacetat) as fixer like suggested by Lemke et al. (2009). This brought the advantage that the pigment would not wear off due to water or mud during the experiment. This was especially important for the longer distances and the runs in wet conditions. When using the pigment in connection with B72 it was crucial to ensure that single seeds would not stick to each other, which would have changed overall results. According to Wichmann et al. (2009) there is no difference to be obsereved between coloured and non-coloured seeds in attachment and proportion of seeds left on the vector at different distances for hiking boots. For this experiment I assume that the same applies to mountain bike tyres. I used UV-torches to detect the seeds on the bicycle.

2.4. Weather conditions

When investigating a potential seed vector, the surrounding condition can play an important role. Taylor et al. (2012) studied the detachment of seeds from cars over distance and found that weather conditions changed attachment and detachment of seeds. Many riders ride their mountain bikes regardless of weather conditions. Hence the weather conditions should also be considered when testing the potential of mountain bikes as seed dispersers.

A pilot study suggested that seed dispersal by mountain bikes is negligible in entirely dry conditions. Within ten runs, undertaken using the described methods and material, there was no seed attached after 5 meters in any of the runs. There was also no sign of seed movement within the first five meters. Therefore dry conditions were not further investigated in the experiment. Seed movement was tested in two different weather conditions: semi-wet and wet. Even after longer periods without precipitation wet/muddy passages can remain on trails (Figure 4.3. in chapter 4). To simulate semi-wet conditions, I added a “puddle” to the set-up . It was located in front of the pick-up area and also measured 213cm · 50cm. It was initially wetted with 2 litres of water and re-wetted after each run with approximately 0.25 litres using a spray bottle. The rest of the test trail remained dry. This was again similar to the study of Wichmann et al. (2009), who first exposed hiking boots to moist soil and then to seeds. The runs for wet condition were carried out on three days. On these dates it had rained between 20 and 22 mm in the 48 hours prior to the testing. During these weather condition the entire trail was wet.

2.5. Tyres

I also tested how two different profile patterns of the tyres affect attachment and detachment of seeds. There were two different tyre models used: a MAXXIS 'Ardent' (2.25 inch) and a MAXXIS 'Advantage' (2.25 inch). Profile depths were 3mm for the 'Ardent' and 3,5mm for the 'Advantage'. The 'Ardent' is advertised as 'do-it-all-tyre' and to be categorized as All Mountain tyre. The 'Advantage' is listed as XC tyre (MAXXIS official website). After five of the ten runs for each distance, I switched the tyre models between front and rear wheel. This was necessary to ensure that differences in overall results would not be caused by one tyre being permanently on the front wheel and the other one being on the impellent rear.

2.6. Survey

Accompanying the experimental data collection on the trail, I also conducted a survey to ascertain riding habits, which possibly affect seed-dispersal, including preferences for certain types of infrastructure and frequency of cleaning the bicycle. A questionnaire with 10 questions was designed (see Appendix: p.39). The survey took place mainly at a mountain bike festival in Freiburg on 18th and 19th of May 2014 and on trails in the Blackforest close to Freiburg between June and July 2014. Several riders were surveyed via email. The majority of participants were local.

2.7. Analysis

I used R (version r-base-core 3.0.2 for Ubuntu) and Rstudio (version 0.98.945 for Linux) for the data analysis. To describe the seed attachment over distance, I compared different models. First a simple linear model in which *lov(distance)* stands for the proportion of seeds left on the mountain bike at a distance. The variables a and b represent the the mean proportion of seeds attached to the mountain bike at d=0 and the detachment rate:

$$lov(distance) = -(b * distance) + a$$

Another model I tested was a single exponential model as used by Tayler et al. (2012) and Wichmann et al. (2009). In this case f, c and q are parameters to control the shape and scale of the models.

$$lov(distance) = e^{f * distance^{c}}$$

The third model was a double exponential model (Bullock et al., 2011; Taylor et al., 2012).

$$lov(distance) = e^{f * e^{q * distance^{c}}}$$

The three models were compared via AIC.

To test the significance of the effects of the different seed species, the weather and different tyres I fitted a generalized linear model (*glm*). To do so the data was transformed with either the natural logarithm (*log)* or the inverse hyperbolic sine (*asinh*). In case of the *log* transformation zero values were replaced by 0.9 (*log*(0)=inf. | *log*(0.9)=-0.11). Models with both transformations were compared. The model with lower the AIC was then used to determine the significance of an additional variable like seed species, weather or tyres. In case of relatively small difference in AIC (ΔAIC) the model using *asinh*-transformation was preferred, since it is not necessary to manipulate the zero values for this transformation.

3. Results

3.1. Seed attachment and detachment over distance

Of the 12500 deployed seeds a mean of 301.1 (± 23.4) for semi-wet conditions and 65.9 (± 5.1) for wet conditions became initially attached to the mountain bike tyres. In one case there were 459 seeds counted. Figure 3.1. shows the proportionate initial attachment relative to the amount of seeds, which were exposed the vector. To calculate the number of exposed seeds I used the following equation:

$$amount\ of\ exposed\ seeds = 1.5\,(\underbrace{tyre\ \ width * \ wheel\, development}_{contact\, area}) * seed\ density$$

The factor for the contact area would be 1.0, given the situation that the rear wheel exactly follows the line of the front wheel; 2.0 if it takes a completely different line. It is rather unlikely that one of these scenarios dominated during the field trials. Therefore, I set the factor to 1.5, representing a more realistic intermediate scenario.

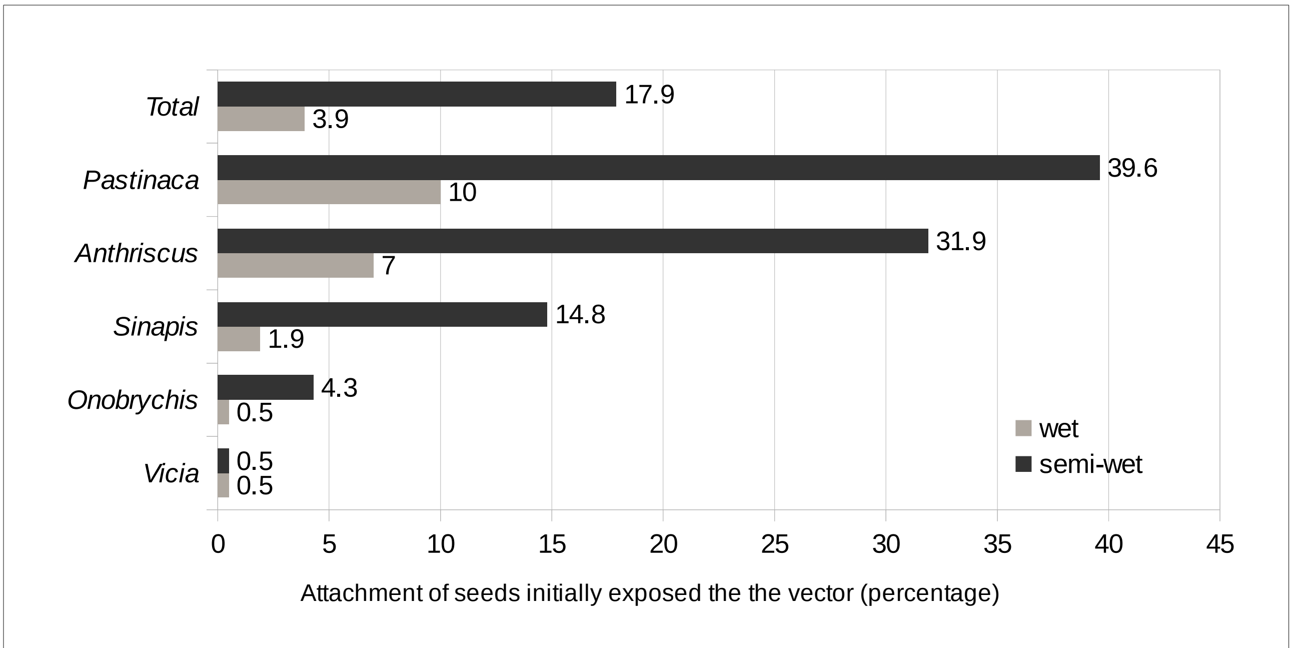


Figure 3.1. *Mean initial attachment in percentage of initially exposed* seeds (see also Table 3.1.1, Appendix). *note the previous formula*

The overall attachment over distance revealed a curved relationship for semi-wet and wet conditions. Of the three models I tested, the linear model delivered the worst fit for both weather conditions. The single exponential model and the double exponential model performed much better

(Table 3.1.2., Appendix). The ΔAIC to the linear model were 142 and 145 in semi-wet conditions with the double exponential model prevailing. In wet conditions ΔAIC were 113 and 115. This time the single exponential model described the data best. 90% detachment thresholds derived from the best fitting model were 16 meters in semi-wet conditions and 15.5 meters. These thresholds were graphically determined. The last seeds remaining on the mountain bike tyres were recorded at 500m and 100m, respectively.

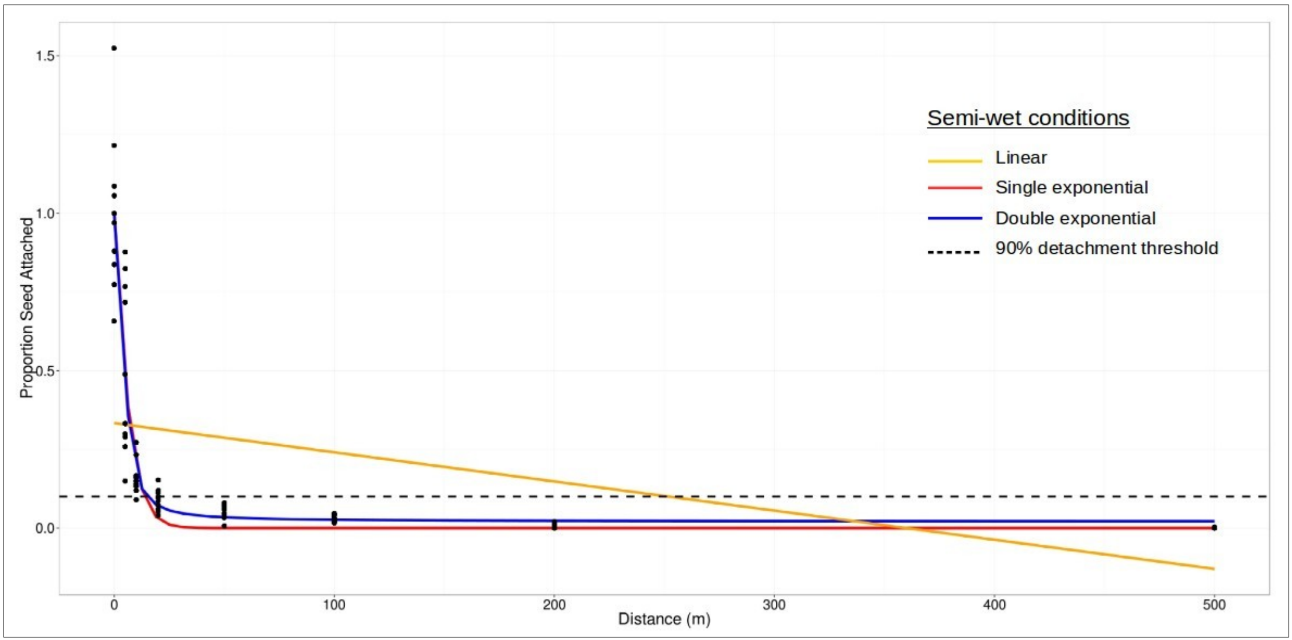


Figure 3.2. *Model fit for the proportion of overall attached seeds over distance in semi-wet conditions (note the legend for the different models).*

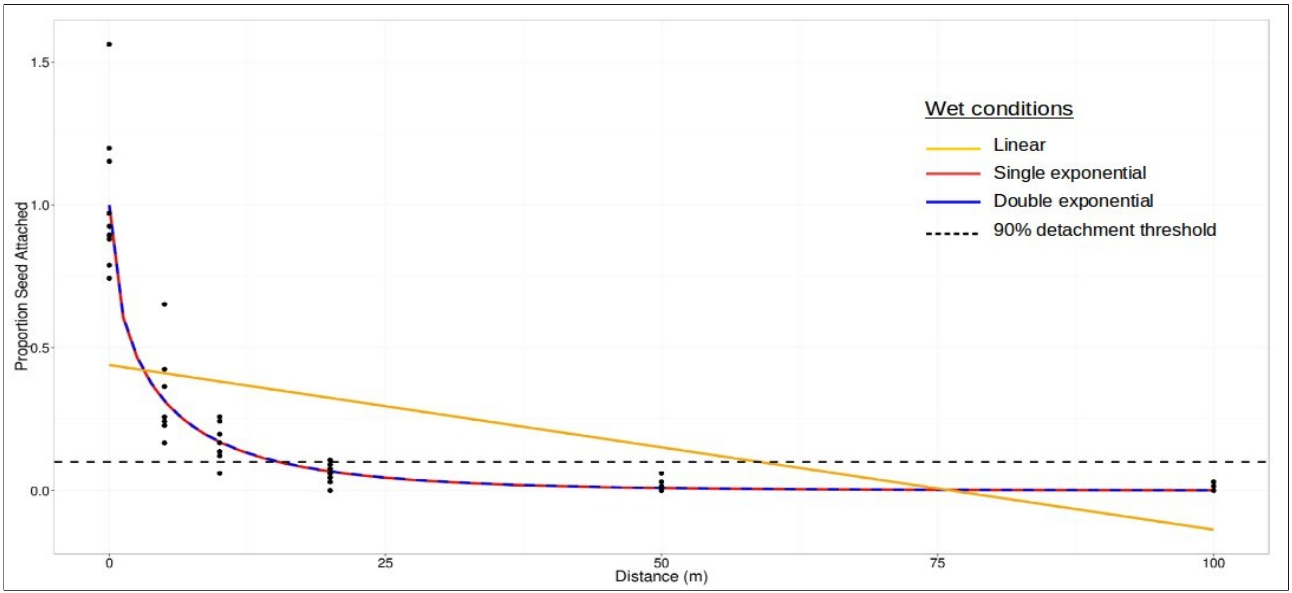


Figure 3.3. *Model fit for the proportion of overall attached seeds over distance in wet conditions (note the different scale on the x-axis compared to the previous figure, the graphs of single and double exponential model are overlaying).*

While the vast majority of seeds were attached to the tyres, there were also seeds found on the bike frame and other parts of the bike. Most of these seeds were attached to the downtube or the underside of the bottom bracket. I also discovered seeds underneath the saddle, on the fork, on the chain and the rims. In contrary to the seeds on the tyres, the number of seeds on frame and other bike parts did not decline with distance but stayed constant. A generalized linear model fitted to the frame attachment data showed no significant decline of seeds attached to the frame over distance (Figure 3.4., Table 3.1.3., Appendix). Within the 70 overall runs in semi-dry conditions I counted 28 seeds on the bike frame. For the 50 runs in wet conditions there were 21 seeds found. Resulting from these figures the chance to have any seed attached on the bike other than on the tyres was 40% in semi-wet conditions and 42% in wet conditions for one run.

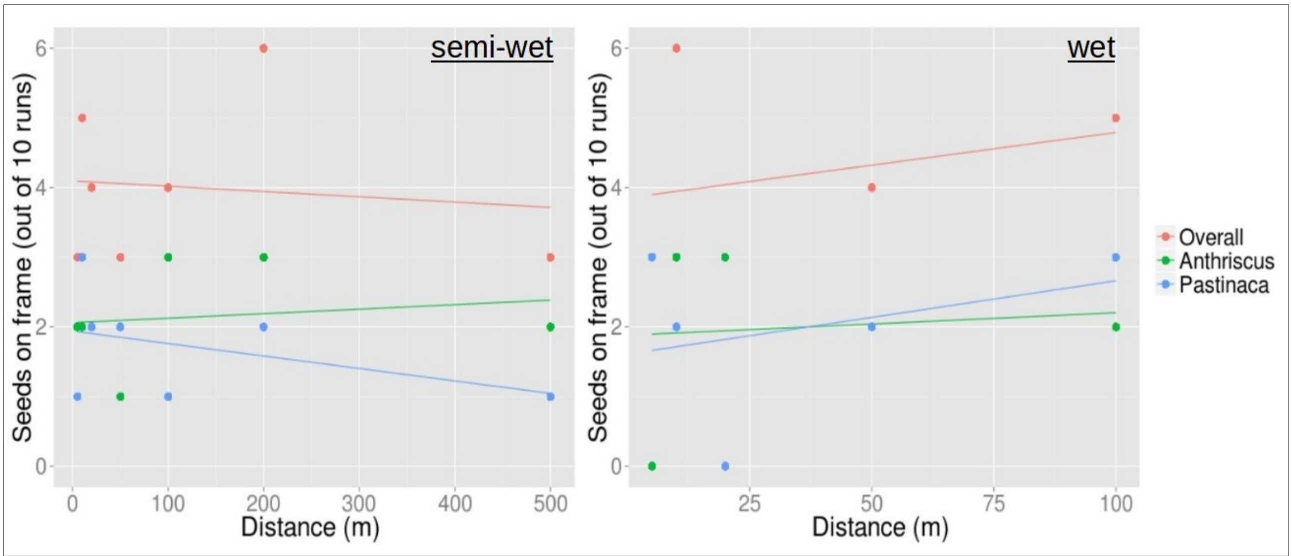


Figure 3.4. *Seed attachment on the bike frame including regression lines. The x-axis shows attached seeds out of the ten runs for the particular distance. The y-axis represents the distance in which the numbers were recorded. Red: Overall seeds, green: Anthriscus, blue: Pastinaca.*

3.2. The effect of seed traits

When comparing the attachment of seeds there was a notable difference between the seed species. In semi-wet conditions *Pastinaca* had the highest numbers of attachment, followed by *Anthriscus*, *Sinapis*, *Onobrychis* and *Vicia*. The same trend could be observed in wet conditions (Figure 3.1. and Table 3.1.1., Appendix).

I also tested the effect of different seed species on detachment (Figure 3.5., Figure 3.6., Table 3.2.1., Appendix). The seed species as additional categorical variable was added to a generalized linear model. The *log* transformation provided a better fit for this model than the *asinh* transformation for both weather conditions (ΔAIC =52 and 76). ANOVA revealed that the model explained 51% of the variance. While the distance explained 23%, 28% could be attributed to the species (48%, 21% and 27% for wet conditions).

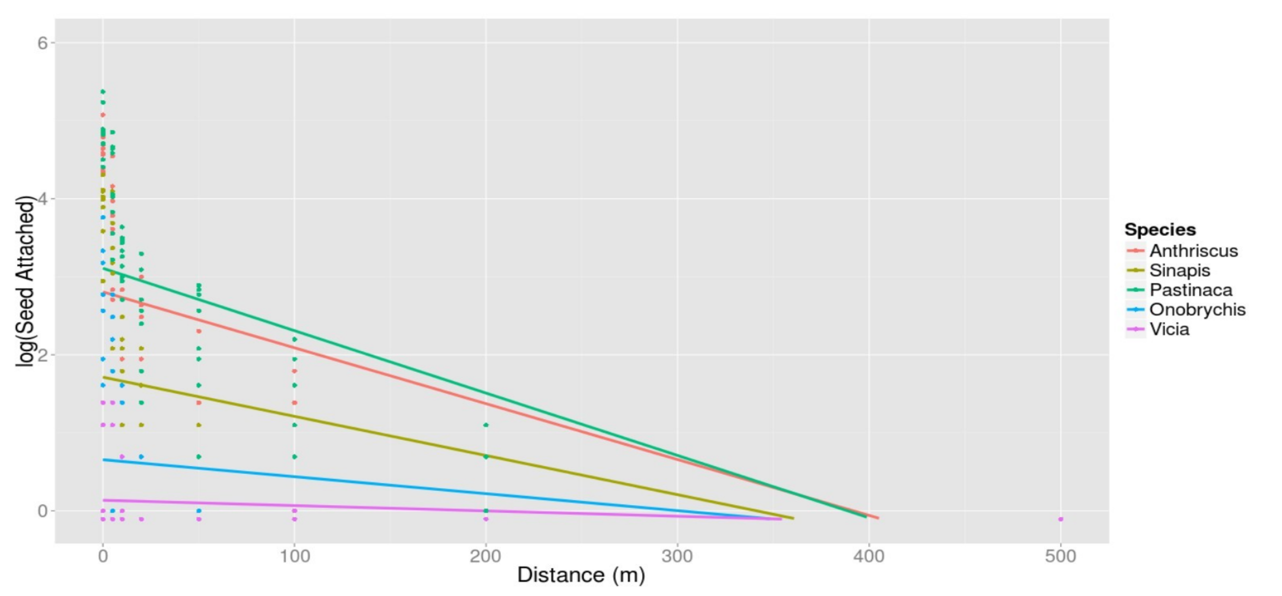


Figure 3.5. *Log(seeds attached) over distance in semi-wet conditions for the different species and their specific regression-lines. (note the legend for the different species).*

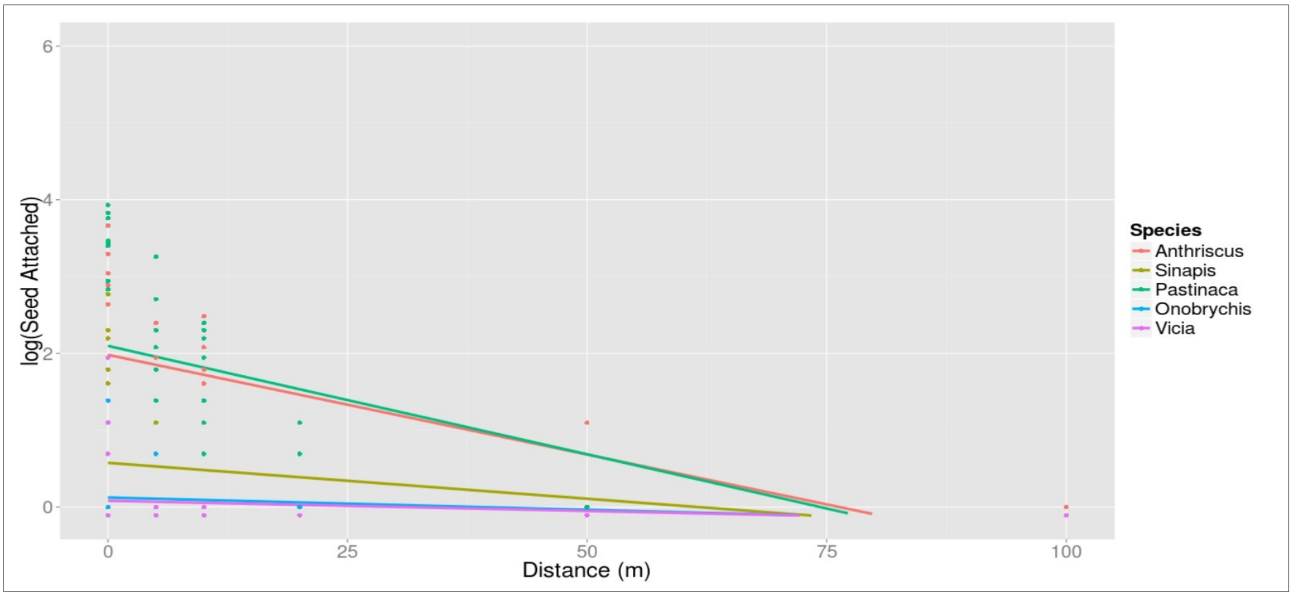


Figure 3.6. *Log(seeds attached) over distance in wet conditions for the different species and their specific regression-lines. (note the legend for the different species).*

When fitting a *glm* with the seed weights as additional continuous variable instead of species (Table 3.2.2., Appendix), the log transformed data proved to deliver the better fit (ΔAIC= 56 and 78). The effect of seed weight was significant in both weather conditions. It was notable that, with 23% and 16%, weight explained less of the model's variance than the species as categorical variable. The same procedure, again with *log* transformed data, was used to also analyse the effect of seed volume as additional continuous variable (Table 3.2.3., Appendix). The seed volume was calculated by multiplying average seed dimensions. The effect of seed volume was found to be significant as well. Seed volume as variable accounted for 14% and 12% of the variance. The seed attachment on the frame seemed to correspond to the trend observed for the attachment on the tyres. With two exceptions, there were only *Anthriscus* and *Pastinaca* attached to the frame to about an equal extent.

3.3. The effect of weather conditions

In addition, I tested if the two weather conditions had an effect on the dispersal potential of mountain biking. First, the data of initial attachment were analysed. For that, I fitted a *glm* with the weather condition as categorical variable (Table 3.3.1., Appendix). The *glm* revealed that weather condition had significant effect on overall initial attachment. The same was done for the five different species (Figure 3.7.).

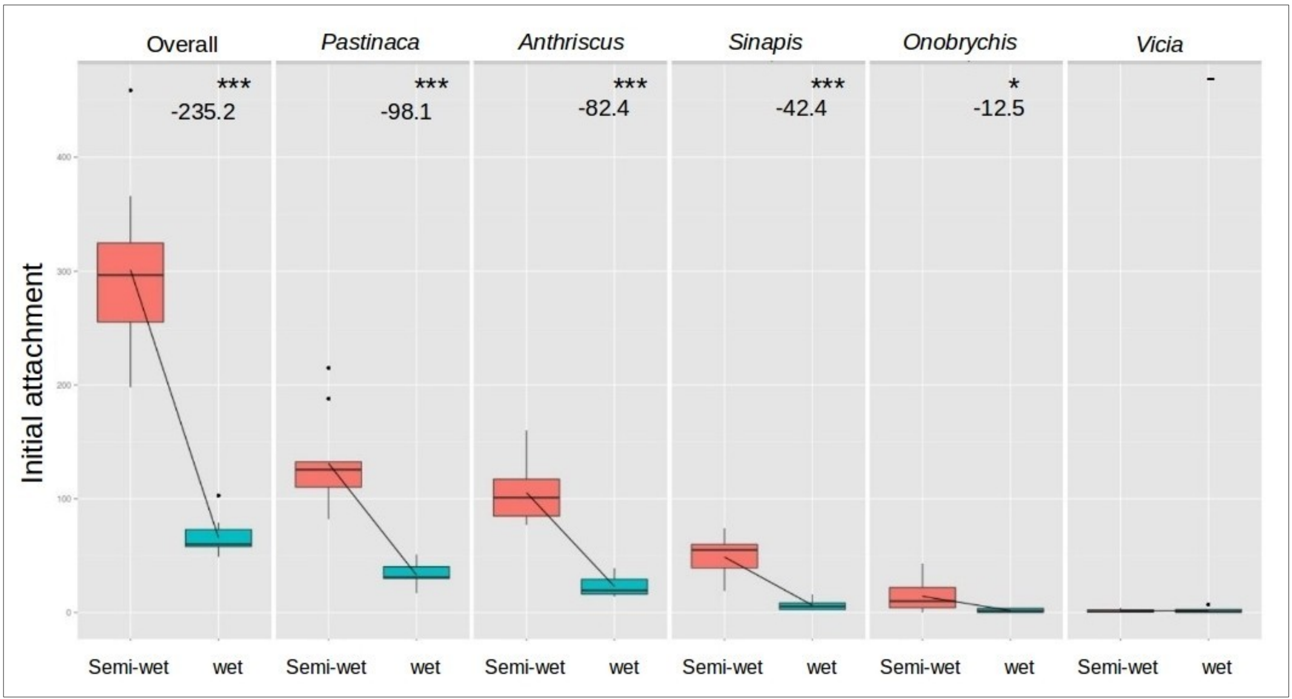


Figure 3.7. *Comparing the initial attachment for semi-wet and wet conditions, stating the particular significance and estimate (***very significant, **significant, *less significant, - not significant).*

For analysing the effect of weather conditions on the overall attachment over distance the *log* transformed data generally provided fits with lower AIC than *asinh* transformed data. The effect of the two different weather conditions, semi-wet and wet, turned out to be significant for the overall attachment. The model explained 59% of variance, with 25% being explained by the weather conditions (Figure 3.8). The same was done for the different seed species (Table 3.3.2., Appendix). The multiple regression comparing seed attachment to the frame in the different weather conditions revealed no significance (Table 3.3.3., Appendix).

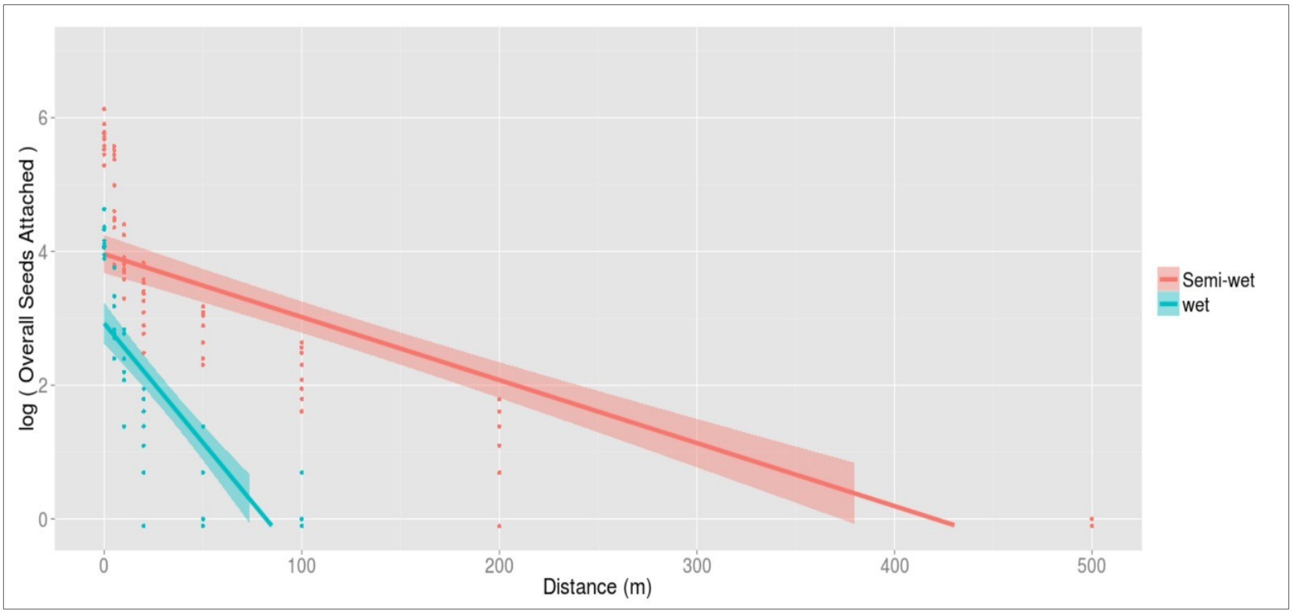


Figure 3.8. *Comparing log(overall attachment) over distance for semi-wet and wet conditions including their specific regression-lines and confidence intervals.*

3.4. The effect of different tyre profiles

To test the effect of tyres, I compared seed attachment over distance between the two tyre models 'Ardent' and 'Advantage' for front and rear wheel in both weather condition (Table 3.4., Appendix). Four models were fitted. Neither the *log* transformed nor the *asinh* transformed data clearly indicated a better fit with the *log* transformation prevailing in three cases and the *asinh* performing better in one case. Due to the small difference I decided in favour of the *asinh* transformation. None of the four datasets evidenced any significance for the effect of different tyres on attachment over distance.

3.5. Survey results

65 mountain bikers participated in the survey. According to the survey results, distances of usual rides range from 10 to 90 km, resulting in a mean of 28.03 ±1.6 km. It was calculated how far the participants ride their bike on average until it is cleaned again, using the following formula:

$$\text{mean distance without cleaning} = \frac{\sum \text{ride length} * \text{cleaning frequency}}{\text{number of participants}}$$

The mean distance until the next cleaning of the bicycle is 70.15 ± 4.1 km, which equates 2.48 average rides. Everyone (100%) passes through forest during his/her rides, followed by grassland/pasture, which is usually passed by 75% of the participants. 46% of mountain bikers regularly encounter urban environment, 22% agricultural land and 18% wetlands. Regarding the question whether the rides lead through any kind of protected area, 7% stated 'always', 86% stated 'sometimes' and 7% answered 'never'. Participants were also asked, which types of infrastructure they prefer on the uphill and downhill passages of their rides. As shown in Figure 3.9., the participating mountain bikers preferred forest roads and designated trails uphill and Social Trails and designated trails downhill. 63% of the participants stated that they generally ride in wet conditions, while 37% declared to do it 'sometimes'. No one stated not to ride at all in wet conditions.

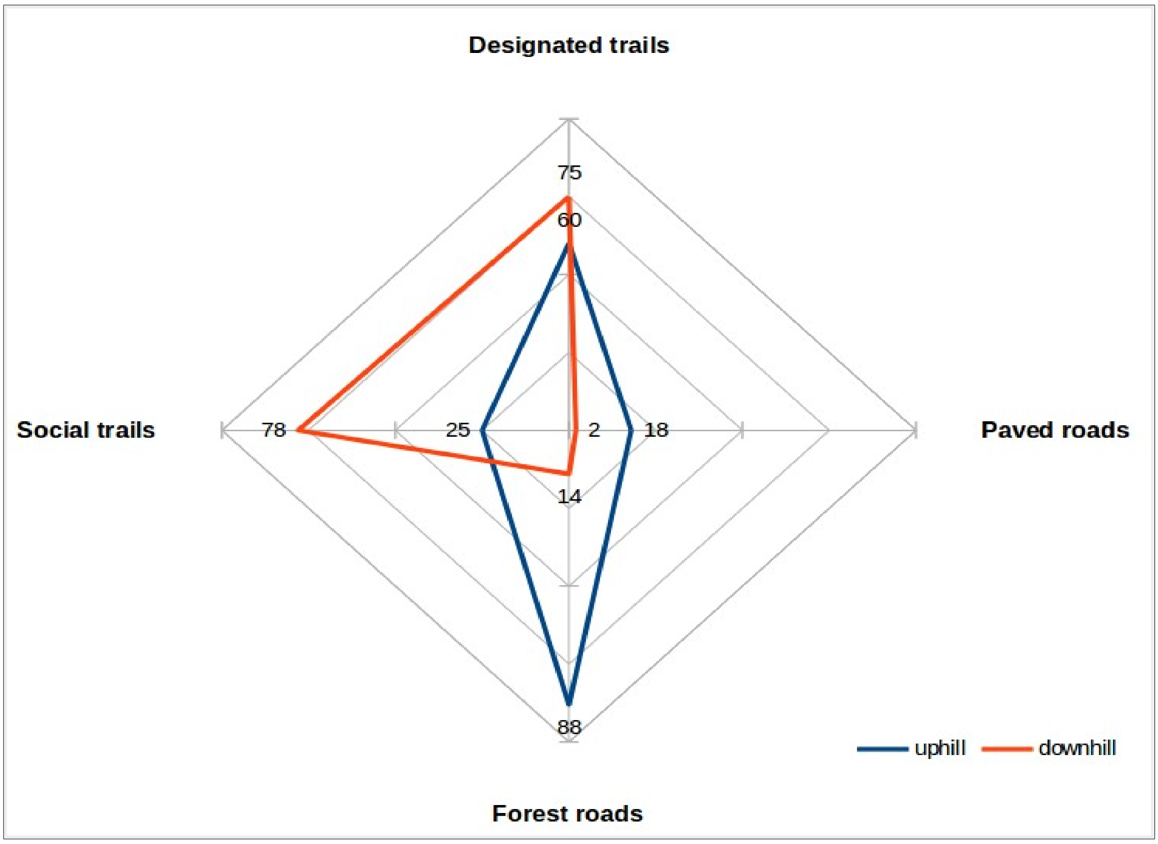


Figure 3.9. *Infrastructural preferences of surveyed mountain bikers, subdivided in uphill and downhill preferences. Results are shown in percentage of nomination. Multiple answers were possible.*

4. Discussion

4.1. The potential of mountain bikes as seed dispersers

4.1.1. Number of seeds attached and range of dispersal

In my experiment the vector, a mountain bike, was exposed to a high number number of seeds. The number of available seeds in natural ecosystems is very likely to be much lower and vary based on local vegetation and season. Therefore, it is not possible to make a general statement about absolute numbers of attachment. In contrary the proportionate attachment of exposed seeds in the experiment is more suitable for a general statement about attachment. Results show (Table 3.1.1., Appendix) that, depending on seed species, up to 39.6% of the seeds exposed to the mountain bike actually attached to it. Based on the initial attachment observed in this study, mountain bikes turn out to indeed have the potential to disperse seeds. The dispersal distance, on the other hand, was considerably shorter than expected in the beginning. While seeds on shoes are dispersed up to 5 km, predictive models even suggest 10 km (Wichmann et al., 2009), the seeds in my experiment reached maximum distances of 500m in semi-wet conditions and 100m in wet conditions, respectively. These results suggest that there is seed dispersal by mountain bikes, but also that it is mostly relevant on a local scale. The models describing the observed data predict that approximately 50%-70% of the initially attached seeds detach within the first five meters. This corresponds to the observations of Wichmann et al. (2009) and Pickering et al. (2011a), who remarked the same to be the case for dispersal on boots and clothing.

4.1.2. Seeds found on the bicycle frame and other bicycle parts

The number of seeds found on the frame and other parts of the bike (Figure 4.2.) were relatively small compared to the number of seeds attached to the tyres. However, it is noteworthy that the number of seeds showed no significant decline over the distances of 500m (semi-wet conditions) and 100m (wet conditions). It seems that seeds attached to parts of the bike other than the tyres are likely to be transported over longer distances. It is not possible to give reliable predictions for the dispersal of these seeds since I

Figure 4.1. *Material stuck to frame after a decent in wet conditions.*

did not collect any information on their detachment rates in this experiment. Although it is likely that some of these seeds will detach over time. Participants of the survey clean their bikes every 70.15 km (every 2.48 rides). If the bike is not cleaned directly after one ride, seeds could be dispersed during the next ride, possibly in a different ecosystem. This could also promote the spread of non-natives and plant invasions since small founder populations are in some cases already sufficient to cause establishment (Gaston et al., 2003; Scott & Kirkpatrick, 2005; Lee & Chown, 2007). It must be considered that my results occurred at speeds between 10 km/h (~6.2 mph) and 15 km/h (~9.3 mph). On downhill passages the speed can be substantially higher. With higher speeds more material, such as soil, litter and seeds, will attach to the frame (personal observation, Figure 4.1.). Therefore, the number of seeds attaching to the bike frame and other bike parts could be underestimated considering the results of my experiment.

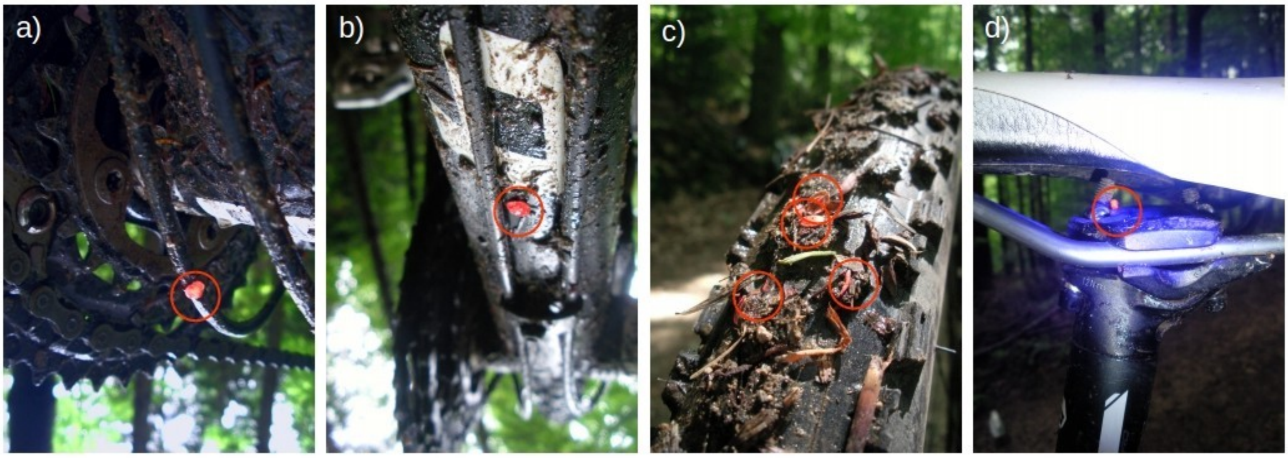


Figure 4.2. *Seeds attached to different parts of the bike: a) cable (bottom bracket), b) downtube, c) tyres, d) saddle.*

4.1.3. Mountain biking as a vector of long-distance dispersal

Single seeds on the tyres reached a maximum distance of 500m in semi-wet conditions and 100m in wet conditions. So there was seed movement recorded only up to landscape scale (Nathan et al., 2008). Whether this can be considered as long-distance dispersal depends on the particular definition of LDD. There are proportional definitions, which define a certain proportion of all seeds that are transported the furthest as LDD. Absolute definitions identify everything above a certain threshold as LDD (Nathan et al., 2008). This threshold is usually set *a priori* and can vary depending on different scenarios (Nathan et al., 2008). Levey et al. (2008) for example defined distances greater than 150m as LDD, since in a fragmented ecosystem, this distance was sufficient to connect different habitat patches. However, this thesis does not refer to a specific ecological setting, because the results are supposed to have a general applicability. Therefore, there is no such threshold for our experiment. So whether the distances reached in this experiment qualify as LDD, depends on the ecological scenario for which mountain biking is considered as seed vector.

Higgins et al. (2003) already mentioned the possibility of multiple dispersal. If one seed is dispersed more than one time by the same or another vector, greater dispersal distances are possible. This could very well also be the case for mountain bikes. In this experiment the probability of a *Pastinaca* seed to become attached to the tyre when being exposed to it was 39.6% on average in semi-wet conditions. Therefore dispersal distances greater than 500m could be possible, if one seed is dispersed by more than one mountain bike. This could happen on popular mountain bike trails with a high frequency of use. Narrow single trails could additionally raise the chance of multiple dispersal. It is also assumable that mountain bikes further disperse seeds that were previously introduced by other vectors, such as hikers, cars and animals. That way, mountain bikes can transport seeds beyond the verges of tourist and car-used infrastructure. Another starting point for non-native seeds are pastures (Pauchard & Alaback, 2004), which are present in many protected areas. The seeds are initially introduced by the grazing animals or additional feed. Once introduced to the pasture crossing or close-by trails channel the following dispersal.

4.2. The effects of seed traits, weather conditions and tyre profiles

Multiple publications state that seed traits have an effect on attachment and detachment (Bullock & Primack, 1977; Lee & Chown, 2009; Wichmann et al., 2009). My results confirm this for the different tested species and suggest that this might also be the case for other species. Both, weight and volume, showed to have a significant effect on attachment and dispersal distance. Lighter seeds like *Pastinaca* and *Anthriscus* tended to attach in larger quantities and be transported for greater distances, while *Vicia,* as the species with the heaviest seeds, attached rarely and was dispersed relatively short. This coincides with other studies. Higgins et al. (2003) predicted that especially small seeded species profit from dispersal by non-standard vectors. Other studies observed that small seeds (grass seeds) have a greater potential to be transported by cars (Schmidt, 1989; Kowarik & Lippe, 2008). In the case of mountain bikes, the effect of seed weight was found to be larger than the effect of seed volume. But both were not able to explain the amount of variance within the used model, which the seed species accounted for. This indicates that there is no single seed property responsible for the different dispersal behaviour of the seed species, but rather a combination of multiple traits (i.e., surface structure of seed coat, hairs or spikes). The species found on the frame show a trend similar to the species recorded on tyres. Except for two exceptions (one *Onobrychis* and one *Vicia*), I found only *Pastinaca* and *Anthriscus* attached to the frame. This suggests again the principle that traits like a low seed weight and low volume favour the attachment to mountain bikes.

After the pilot study did not reveal any considerable dispersal in dry conditions, my study focused on dispersal in semi-wet and wet conditions. Not only were both tested weather conditions found out to favour seed dispersal by mountain bike, but also to do so to a different extent. There were significantly more seeds attaching to the tyres and being transported for significantly greater distances in semi-wet conditions. In this case semi-wet conditions meant: The seeds were exposed to a wet/muddy tyre and than transported in predominantly dry conditions. Yet it is not safe to say that there will be more mountain-bike-caused dispersal in semi-wet conditions. These conditions are heterogeneous: Dry and wet passages alternate on the trail and wet or moist sections will be followed by dry surface (Figure 4.3.). In this conditions the tyre will have to be wet when passing seeds. In contrast, the homogeneously wet conditions simulated in the experiment apply to the whole trail in case of rain. So it is possible that overall seeds will be dispersed more in wet conditions. On the other hand, I assume that the greatest dispersal distances will occur in heterogeneous semi-wet conditions, so for example some time after rain events, near watersheds, on the moist northern flank of mountains or in wet- and swamplands.

Figure 4.3. *Examples of heterogeneous conditions encountered on mountain bike trails around Freiburg.*

In mountain biking it is common to ride different tyres on the front and the rear. So the opportunity arose to test the effect of two different tyres. Although the analysis of my data did not show any significance of the two different tyre models in neither weather condition, this does not necessarily prove that tyre choice is not relevant for seed dispersal. This experiment just cannot confirm an effect caused by tyres. However, the two tyres tested were in many ways similar to each other and do not represent the range of tyres used for different riding styles.

4.3. Interpreting the survey results

The mountain bikers participating in the survey were mostly local. Therefore, the information gathered from the results is far from being universally valid. Also my survey only had 65 participants and it is not certain that the acquired results are really representative for the Blackforest. However, they illustrate well, why it is so important to gather information about the local mountain bikers and their habits to rate the potential of mountain bikes as dispersal vectors. The experiment revealed that seeds attached to the frame have the potential to stay on the bike for more than 500m. If the bicycle is not cleaned in between rides the seeds could be transported for long distances. The average survey participant rode his/her bike 70.15 km before cleaning it again. This equates 2.48 average rides. That means, a seed which attaches to the bike on one ride could detach on the next ride, possibly in an entirely different region. It also emerged that a rather substantial proportion of mountain bikers (46% or 22%, respectively) regularly passes through urban or agricultural environment, where non-native plant species introduced by humans are widely abundant (Kowarik & Lippe, 2008). This might not be the case in other areas, but probable in the periphery of larger settlements. The infrastructure preferences show that the surveyed mountain bikers indeed use Social Trails to a large extent. Furthermore, it can be also seen that mountain bikers use a variety of infrastructure, including paved streets. This suggests that they can act as a connecting vector between different types of infrastructure, which links them to different kinds of other potential vectors. The survey results confirm that mountain bikes are frequently ridden in protected areas. Supposedly protected areas are especially attractive due to the enhanced nature experience. Mountain bikers do not seem to avoid rainy or wet conditions, it is important to consider and evaluate dispersal in different weather conditions.

4.4. Indirect effects of mountain biking on seed dispersal

Besides the mountain bike itself, seeds can also become attached to the rider him/herself, e.g. his/her clothing or equipment. In various studies it was discovered that humans have a high potential to act as a selective seed vector (Pickering et al., 2011a). Studies have reported 228 species of which seeds were detected attached to clothing and equipment (Pickering & Mount, 2010). Usually, single trails are very narrow (<50cm) and, depending on the surrounding vegetation, seeds can attach when a passing mountain biker brushes the bordering plants. One study discovered that clothing is able to hold attached seeds for more than 5000m (Pickering et al., 2011a). Especially socks, worn in combination with shorts, seem to transport seeds (Lee & Chown, 2009). Mount & Pickering (2009) found they (socks) collect large numbers of up to 500 seeds per sock. Trails, particularly the ones in heavy terrain, are constantly changing. Riders will encounter branches or whole trees blocking the passage. In dry conditions or after heavy rainfalls, erosion can make trail sections impassable on bike. Very challenging or simply too steep sections can also individually hinder riders from staying on the bike. In general, mountain bikers are frequently forced to dismount and continue on foot, pushing or carrying the bike for a short distance. On these occasions, mountain bikers' shoes and clothing can take up seeds. Different from the ones for road cyclists, shoes designed for mountain biking feature a distinct profile similar to hiking boots. Seeds were observed to stay attached to shoes (hiking boots) for up to 5000m while walking. Quantified HMD kernels even suggest that distances to up to 10 000m are possible (Wichmann et al., 2009). The same study even explicitly pointed out that vehicles could aid the transport of seeds stuck on human clothing and shoes. In case of mountain biking, the rider is likely to mount the bike just after walking a short distance and continue biking. In this case, the attached seed will travel an indefinite distance before there is the chance of detachment. Dispersal distances could therefore be even greater than the ones observed in the mentioned study. Many items commonly used by mountain bikers, such as protective gear, daypacks and clipless cycling shoes feature Velcro®. The structure of Velcro® causes certain kinds of seed to attach very strongly to it. Lee & Chown (2009) observed that it has a significantly lower rate of detachment than other clothing items and is therefore able to transport seeds over very long distances. Velcro® was highlighted as biosecurity risk in the context of expeditions to remote and sensitive ecosystems (Whinam et al., 2005).

Mountain biking promotes the unintentional dispersal of seeds on clothing by enabling them to cover even relatively long distances quickly. Consequently, many mountain bike specific clothing items like protective gear and cycling shoes have an above average tendency to attach and transport seed. Tough this is not directly subject to this research it needs to be taken into account when considering the role of mountain biking in seed dispersal.

Mountain biking also shapes its environment in ways that are important for the processes following the dispersal. These must be considered when looking at mountain biking as a vector of plant dispersal. They can aid the establishment of introduced species by providing favourable conditions. The extent of the environmental impacts of mountain biking is still lively discussed, but most of present literature agrees that the physical on-site impacts of mountain biking are relatively severe (Day & Turton, 2000; Cessford, 2003; Pickering et al., 2011b). Common results are on-trail erosion (Day & Turton, 2000) and trail widening (Pickering et al., 2011b). Many trails feature steep slopes, which are sensitive to physical stress and therefore prone to erosion (Day & Turton, 2000). Although most sources agree that mountain biking is the cause for increased on-site erosion this is not entirely certain yet. In an experiment Thurston & Reader (2001) compared the erosion effects caused by hikers and mountain bikers. They found out that mountain bikes do not cause significantly more erosion than hikers. The study highlights that mountain bike trails are often especially disturbed. However, many mountain bikers specifically choose to ride on very disturbed trails for technical aspects while not necessarily being the initial cause for the disturbance. In either way, the appearance of mountain biking and on-site erosion seems to be correlated. On maintained trails, one option to limit erosion is hardening the trail surface (Turton, 2005). However, in extensive trail networks this practice is often not practicable. One important source of disturbance on mountain bike trails is the construction of technical features like obstacles (Pickering et al., 2010a). This often involves clearing of vegetation and turbation of the soil. Material brought to the site for trail construction acts as an additional source of non-native seeds (Pickering et al., 2010a). The degree of disturbance relative to use intensity is often times greatest on social/informal trails, because they are rarely properly constructed and lack treatments like hardening. These trails are mostly unauthorized and the construction of the trail and technical features progresses uncontrolled. At this point it should be mentioned that different riding styles (CX, All Mountain, Freeride, Downhill, etc.) affect the trail to a varying extent (Webber, 2007; Newsome & Davis, 2009). This is mostly due to differences in riding techniques - especially braking, speed, choice of terrain and choice of tyres.

Most alien species are not capable of colonizing in a natural environment because many of them are pioneer species, which are not able to prevail competing with well developed and long established vegetation (Pauchard & Alaback, 2004). Closed canopy and litter layer prevent the establishment (Parendes & Jones, 2000; Arevalo et al., 2005). But when they are introduced to a disturbed environment they can be able to colonize (Cadenasso & Pickett, 2001). Research often observed that non-native plant species are especially abundant in disturbed habitats (Humphries et al., 1991; Thurston & Reader, 2001; Pickering & Hill, 2007; Christen & Matlack, 2008). The damage of soil and vegetation caused by mountain biking is likely to favour weeds in general and could also promote non-native species (Pickering et al., 2010b). Modified conditions on trails can promote the establishment of seeds that were introduced on mountain bike tyres, other bike parts or the rider's clothing and equipment. They also aid the establishment of seeds that detached from other human or non-human vectors. The creation of linear structures like trails also supports expansion of certain species simply by providing a linear habitat, which channels also the natural dispersal (Kowarik, 2003). The stress of mountain biking itself, on the other hand, most likely impedes the establishment of any vegetation anyway, which probably cancels out the promoting effect of mountain bike trails in many cases. Additionally the erosion on trails can create linear channels, which change hydrology (Keller, 1990). The modified drainage causes a difference in propagule movement and facilitates downhill seed transport by water.

4.5. Management implications

Before considering management strategies, there must be determined whether the managing of mountain biking as dispersal vector is necessary. It should be locally investigated which abundant species would profit from dispersal by mountain bikes and how these effect the ecosystem and its functions. In some cases additional dispersal might even be beneficial. It needs to be assessed if the area is prone to erosion and other impacts mountain biking can have. Also it should be considered to what extent the area is accessed by mountain bikers and which infrastructure they use. Only then it can be decided if it is necessary to pursue management strategies.

The existence and use of Social Trails is a key issue in managing mountain biking as a dispersal vector. To determine which areas are affected by the vector, it is important to know where the vector is able to go. Most Social Trails are unknown to the managing authorities. Discovered and destroyed Social Trails are often quickly rebuilt or replaced by new ones. As Pickering et al. (2010a) stated, Social Trails are the result of a combination of increasing demand and a slow response of managing authorities to this demand. An appropriate measure in order to better control mountain biking would be to mark designated mountain biking trails, which meet the demands of mountain bikers. From the perspective of nature conservation, concentrating human activity is an effective strategy to limit the environmental impacts in an area (Turton, 2005).

In case of already existing plant invasions or known populations of species that should be deterred from further spreading, the cleaning of tyres or even the whole mountain bike can be helpful. Some countries with pristine ecosystems and a high concentration of endemic species (e.g. New Zealand) already insist on the cleaning of equipment before entering the country to prevent plant invasions from overseas. The 'Mountain Bikers Code' developed by the Mountain Bike Association of New Zealand advises to clean the bike to prevent the spreading of weeds (Mountain Bike Association of New Zealand). This can be seen as positive example of ecologically conscious management.

4.6. Further research suggestions

Comprehending the mechanisms of dispersal is crucial for understanding and therefore mitigating plant invasions. Being able to prevent invasions or at least controlling them in early stages is more effective than trying to eradicate them later (Christen & Matlack, 2008). Research is the key to comprehending dispersal and will contribute to successfully mitigate or manage plant invasions.

Due to limited time and resources, this study only tested seed dispersal using five different species. Since with these five species seed traits were discovered to make a significant difference in attachment and detachment, researching the effect of a greater variety of traits seems promising. Especially research on dispersal of smaller and lighter seeds should be interesting.

Also, this experiment only tested speeds of 10 km/h (~6.2 mph) to 15 km/h (~9.3 mph). However, there are reasons to assume that the speed of the mountain bike has influence on the attachment rates of seeds. Knowledge about the attachment and detachment rates at different speeds would be a step towards modelling complex dispersal kernels for mountain bikes.

Mountain biking in its facets is not uniform. There are many riding styles, which substantially differ in riding speeds, terrain choice and material. Generally there is more research on environmental impacts of the various riding style needed. The differences between them could have direct as well as indirect effects on seed dispersal by mountain bikes. Therefore I advise additional research on different riding styles concerning their environmental impacts, including their potential to disperse plant seeds.

So far, there has been no study assessing the abundance of weeds on and around mountain bike specific trails (Pickering et al., 2010b). As mentioned before, the role of mountain biking as a dispersal vector depends on local ecological conditions. Consequently in order to successfully estimate the consequences of seed dispersal by mountain bikes, the local conditions must be assessed. Nature-based sports and activities in general, mountain biking in particular, are globally gaining popularity and especially protected areas are increasingly frequented. To ensure the sustainable use of these areas, there needs to be more research on unintentional human-mediated seed dispersal.

5. Conclusion

This study aimed to evaluate the potential of mountain bikes to act as a vector of dispersal. Results of the experiment show that seeds in fact do attach to mountain bike tyres in varying quantities and are transported up to 500m. Thus, mountain biking needs to be considered as potential vector of dispersal. It turned out that this potential substantially depends on the surrounding conditions. The weather conditions influence attachment rates and maximum dispersal range. Different seed species also significantly vary in their tendency to be dispersed by mountain bikes, indicating that mountain biking acts as a selective vector. The effect of seed weight and volume suggests that small and light seeds are dispersed in greater quantities and for wider distances. It emerged that seeds attached to the bike frame and other parts have the potential to be dispersed over longer distances. The survey confirms that local mountain bikers do ride in protected areas and in rainy conditions. They pass a variety of landscapes and use diverse infrastructure. The use of Social Trails is expectedly popular. This flexibility in movement makes it harder to control the environmental impacts such as the spread of invasive species. In the future, mountain biking's potential to disperse seeds should be locally evaluated, taking local vegetation, surrounding conditions and attendant mountain bikers into account. In general there is more research required in the field of HMD. Mountain biking deserves more attention as dispersal vector, especially since it is becoming increasingly popular worldwide.

References

Scientific publications

Arevalo, J., Delgado , J., Otto, R., Naranjo, A., Salas, M., Fernandez-Palacios, J. (2005). *Distribution of alien vs. native plant species in roadside communities along an altitudinal gradient in Tenerife and Gran Canaria*. Perspectives in Plant Ecology, Evolution and Systematics 7, 185-202.

Arnberger, A. (2006). *Recreation use of urban forest: an iner-area comparison*. Urban Forest, Urban Green 4, 135-144.

Asner, G.P., Vitousek, P.M. (2005). *Remote analysis of biological invasion and biochemical change*. Proceedings of the National Academy of Sciences 102, 4383-4386.

Becker, T., Dietz, H., Billeter, R., Buschmann, H., Edwards, P.J. (2005). *Altitudinal distribution of alien plants species in the Swiss Alps*. Perspectives in Plant Ecology, Evolution and Systematics 7, 173- 183.

Brandes, D., Nitzsche, J. (2007). *Verbreitung, Ökologie und Soziologie von Ambrosia artemisiifolia L. in Mitteleuropa*. Tuexenia 27, 167-194.

Bullock, J.M., Galsworthy, S.J., Manzano, P., Poschlod, P., Eichberg, C., Walker, K., Wichmann, M.C. (2011). *Process-based functions for seed retention on animals: a test of improved descriptions of dispersal using multiple data sets*. Oikos 120, 1201-1208.

Bullock, S.H., Primack, R.B. (1977). *Comparative experimental study of seed dispersal on animals*. Ecology 58, 681-686.

Butler, J.L. (2003). *Biophysical and Psychosocial Impacts of Undesignated Walking Tracks Within the Wet Tropics World Heritage Area*. Unpublished Honours Thesis, James Cook University , Cairns.

Cadenasso, M.L., Pickett, S.T.A. (2001). *Effects of edge structure on the flux o species into forest interiors*. Conservation Biology 15, 91-97.

Campbell, J.E., Gibson, D.J. (2001). *The effect of seeds of exotic species transported via horse dung on vegetation along trail corridors*. Plant Ecology 157, 23-35.

Cessford, G. (2003). *Perception and reality of conflict: walkers and mountain bikes on the Queen Charlotte Track in New Zealand*. Journal of Nature Conservation 11, 310-316.

Christen, D.C., Matlack, G.R. (2008). *The habitat and conduit functions of roads in the spread of three invasive plant species*. Biological Invasions 11, 453-465.

Cordell, K.H. (2008). *The latest trends on nature-based outdoor recreation*. For. History Today (Spring), 4-10.

Couveur, M., Christiaen, B., Verheyen, K., Hermy, M. (2004). *Large herbivores as mobile links between isolated nature reserves through adhesive seed dispersal*. Applied Vegetation Science 7, 229-236.

Davidson, D.E., Morton, S.R. (1981). *Myrmecochory in some plants (F. Chenopodiaceae) of the Australian arid zone*. Oecologia 50, 357-366.

Day, T.J., Turton, S.M. (2000). *Ecological impacts of recreation along mountain bike and walking tracks. In Bentrupperbäumer, J.M. and Reser, Impacts of Visitation and Use in the Wet Tropics of Queensland World Heritage Area, Stage 2*. Wet Tropics Management Authority and Rainforest CRC. Cairns, 143-152.

Gaston, K.J., Jones, A.G., Hänel, C., Chown, S.L. (2003). *Rates of species introduction to a remote oceanic island*. Proceedings of the Royal Sociaty B 270, 1091-1098.

Gomez, C., Espadaler, X. (1998). *Myrmecochorous dispersal distances: a world survey*. Journal of Biogeography 25, 573-580.

Gower, S.T. (2008). *Are horses responsible for introducing non-native plants along forst trails in the eastern United States?*. Forest Ecology and Management 256, 997-1003.

Hales, R., Kiewa, J. (2007). *South east Queensland outdoor recreation demand study 2007*. Brisbane,Qld:Department of Sport and Recreation.

Higgins, S., Nathan, R., Cain, M. (2003). *Are Long-Distance Dispersal Events in Plants usually caused by nonstandard Means of Dispersal?*. Ecology 84 (8), 1945-1956.

Hollenhorst, S., Schuett, M.A., Olsen, D., Chavez, D. (1995). *An Examination of the Characteristics, Preferences, and Attitudes of Mountain Bike Users of the National Forests*. Journal of Park and Recreation Administration 13 (3), 41-51.

Hughes, L., Dunlop, M., French, K., Leishmann, M.R., Rice, B., Rogerson, L.A., Westoby, M. (1994). *Predicting dispersal spectra: a minimal set of hypotheses based on plant attributes*. Journal of Ecology 82, 933-950.

Humphries, S.E., Groves, R.H., Mitchell, D.S. (1991). *Plant Invasions of Australian Ecosystems*. Canberra: Australien National Parks and Wildlife Service..

Johnston, F.M., Johnston, S.W. (2004). *Impacts of Road Disturbances on Soil Properties and on Exotic Plant Occurrence in Subalpine Areas of the Australian Alps*. Arctic, Antarctic and Alpine Research 36 (2), 201-207.

Johnston, F.M., Pickering, C.M. (2001). *Alien Plants in the Australian Alps*. Mountain Research and Development 21 (3), 284-291.

Karger, L. (1997). *Ipacts of Trampling on Vegetation and Soils Along Low and High Use Walking Tracks at Mossman Gorge, Northeast Queensland* . Unpublished Honours Thesis, James Cook University, Cairns.

Keller, K.J.D. (1990). *Mountain Bikes on Public Lands: A Manager's Guide to the State of Practice*. Bicycle Federation of Amerca, Washington D.C..

Kelly, C.L., Pickering C.M., Buckley, R.C. (2003). *Impacts of tourism on threatened plant taxa and communities in Australia*. Ecological Management & Restoration 4 (1), 37-44.

Kowarik, I. (2003). *Human agency in biological invasions: secondary release foster naturalization and population expansion of alien plant species*. Biological Invasions 5, 293-312.

Kowarik, I., Lippe, M. von der (2008). *Zu Mechanismen der Linienmigration von Pflanzen*. Braunschweiger Geobotanische Arbeiten 9, 363- 375.

Lee, J.E., Chown, S.L. (2009). *Breaching the dispersal barrier to invasion: quantification and management*. Ecological Applications 19 (7), 1944-1959.

Lee, J.E., Chown, S.L. (2007). *Mytilus on the move: transport of an invasive bivalve to the Antarctic*.. Marine Ecology Progress Series 339, 307-310.

Lemke, A., Kowarik, I., von der Lippe, M. (2009). *New opportunities for an old method: usingfluorescent colours to measure seed dispersal*. Journal of Applied Ecology 46, 1122–1128.

Levey, D.J., Tewksbury, J.J., Bolker, B.M. (2008). *Modelling long-distance seed dispersal in heterogeneous landscapes* . Journal of Ecology 96, 599-608.

Lippe, M. von der, Kowarik, I. (2008). *Do cities export biodiversity? Traffic as dispersal vector across urban-rural gradients*. Diversity and Distributions 14, 18-25.

Lippe, M. von der, Kowarik, I. (2007). *Long-Distance Dispersal of Plant by Vehicles as a Driver of Plant Invasions*. Conservation Biology 21 (4), 986-996.

Lonsdale, W., Lane, A. (1994). *Tourist Vehicles as Vectors of Weed Seeds in Kakadu National Park, Northern Australia*. Biological Conservation 69, 277-283.

Lonsdale, W. (1999). *Global patterns of plant invasions and the concept of invasability* . Ecology 80, 1522-1536.

Mack, R.N., Simberloff, D., Lonsdale, W.M., Evans, H., Clout, M., Bazzaz, F.A. (2000). *Biotic invasions: causes, epidemiology, global consequences, and control*. Ecological Applications 103, 689-710.

Marion, J.L., Wimpey, J. (2007). *Environmental impacts of mountain biking: science review and best practices. In Webber, P., Managing mountain biking, IMBA's guide to providing great riding*. International Mountain Bicycling Association (IMBA), Boulder, 94-111.

Mason, P., Lebermann, S. (2000). *Local planning for recreation and tourism: a case study of mountain biking from New Zealand's Manawatu Region*. Journal of Sustainable Tourism 8, 97-115.

Mc Dougall, K.L., Morgan, J.W., Walsh, N.G., Williams, R.J. (2005). *Plant invasions in treeless vegetation of the Australian Alps*. Perspectives in Plant Ecology, Evolution and Systematics 7, 159-171.

Millenium Ecosystem Assessment (2005). *Ecosystems and human well-being: biodiversity synthesis*. World Resources Institute, Washington, D.C., USA.

Morey. E.R., Buchanan, T., Waldmann, D.M. (2002). *Estimating the benefits and costs to mountain bikers of changes in trail characteristics, access fees, and site closures: choice experiments and benefits transfer*. Journal of Environmental Management 64, 411-422.

Mount, A., Pickering C.M. (2009). *Testing the capacity of clothing to act as a vector for non-native seed in protected areas*. Journal of Environmental Management 91, 168-179.

Nathan, R., Schurr, F., Spiegel, O., Steinitz, O., Trakhtenbrot, A., Tsoar, A. (2008). *Mechanisms of long-distance seed dispersal*. Trends in Ecology and Evolution 23 (11), 638-647.

National Survey on Recreation and the Environment (2000). . Outdoor Recreation Participation in the United States. USDA Forest Service, Oregon, USA.

Newsome, D., Davis, C. (2009). *A case study in estimating the area of informal trail development and associated impacts caused by mountain bike activity in Jon Forrest National Park, Western Australia*. Journal of Ecotourism 8, 237-253.

Parendes, L.A., Jones, J.A. (2000). *Role of light availabiliy and dispersal in alien plant invasion along roads and streams in the H.J.Andrews Experimental Forest, Oregon*. Conservation Biology 14, 64- 75.

Pauchard, A., Alaback, P.B. (2004). *Influence of elevation, land use and landscape context on patterns of alien plant invasions along roadsides in protected areas of south-central Chile*. Conservation Biology 18, 238-248.

Pauchard, A., Kueffer, C., Dietz, H., Daehler, C.C., Alexander, J., Edwards, P.J., Arevalo, J.R., Cavieres, L.A., Guisan, A., Haider, S., Jakobs, G., McDougall, K., Millar, C.I., Naylor, B.J., Parks, C.G., Rew, L.J., Seipel, T. (2009). *Ain't no mountain high enough: plant invasions reaching new elevations*. Front. Ecol. Environ. 7, doi: 10.1890/080072.

Pickering, C.M., Castley. J.G., Hill, W., Newsome, D. (2010a). *Environmental, safety and management issues of unauthorised trail technical features for mountain bicycling*. Landscape and Urban Planning 97, 58-67.

Pickering, C.M., Hill, W. (2007). *Impacts of recreation and tourism on plant biodiversity and vegetation in protected areas in Australia*. Journal of Environmental Management 85, 791-800.

Pickering, C.M., Hill, W., Newsomen, D., Leung, Y. (2010b). *Comparing hiking, mountain biking and horse riding impacts on vegetation and soild in Australia and the United States of America*. Journal of Environmental Management 91, 551-562.

Pickering, C.M., Mount, A. (2010). *Do tourists disperse weed seed? A global review of unintentional human-mediated terrestrial seed dispersal on clothing, vehicles and horses*. Journal of Sustainable Tourism 18 (2), 239-256.

Pickering, C.M., Mount, A., Wichmann, M.C., Bullock, J.M. (2011a). *Estimating human-mediated dispersal of seeds within an Australian protected area*. Biological Invasions 13, 1869-1880.

Pickering, C.M., Rossi, S., Barros, A. (2011b). *Assessing the impacts of mountain biking and hiking on subalpine grassland in Australia using an experimental protocoll*. Journal of Environmental Management 92, 3049-3057.

Pickering, C.M., Hill, W., Bear, R. (2007). *Indirect impacts of nature based tourism and recreation: Association between infrastructur and exotic plants in Kosciuszko National Park*. Journal of Ecotourism 6, 146-157.

Price, M.E. (2006). *Global change in mountain regions*. Duncow, UK: Sapiens Publishing,.

Riccardi, A. (2007). *Are modern biological invasions an unpredecendent form of global change?* Conservation Biology 21, 329-336.

Schmidt, W. (1989). *Plant dispersal by motor cars*. Vegetatio 80, 147-152.

Schraml, U. (2008). *Willkommen in der schönen neuen Welt des Geocaching*. Pro Wald,März 2008: 34-36.

Schraml, U., Hotz, S., Selter, A. (2014). *Walderholung mit und ohne Bike? Eine Befragung von Wanderern und Mountainbikern im Schwarzwald*. Arbeitsbericht 01/2014ISSN 1865-3863.

Scott, J.J., Kirkpatrick, J.B. (2005). *Changes in Subantarctic Heard Island Vegetation at Sites Occupied by Poa annua, 1987-2000*. Arctic, Antarctic, and Alpine Research 37(3), 366-371.

Scott, J.M., Frank, W., Davis, R., et al. (2001). *Nature reserves: do they capture the full range of America's biological diversity?*. Ecological Applications 11, 999-1007.

Smith, R.A., Turton, S.M. (1995). *Environmental Impacts on Campsites and Walking Tracks in and Alongside the World Heritage Daintree National Park* . Wet Tropics Management Authority, Cairns, Australia.

Spellerberg, I. (1998). *Ecological effects on roads and traffic: a literature review*. Global Ecology and Biogeography Letters 7, 317-333.

Taylor, K., Brummer, T., Taper, M., Wing, A., Rew, L. (2012). *Human-mediated long-distance dispersal: an empirical evaluation of seed dispersal by vehicles*. Diversity and Distributions 18, 942-951.

Thurston, E., Reader R.J. (2001). *Impacts of Experimentally applied Mountain Biking and Hiking on Vegetation and Soil of a Deciduous Forest*. Environmental Management Vol.27 No.3, 397-409.

Tuerke, M., Heinze, E., Andreas, K., Svendsen, S.M., Gossner, M.M., Weisser, W.W. (2010). *Seed consumption and dispersal of ant-dispersed plants by slugs*. Oecologia 163, 681–693.

Turton, S.M. (2005). *Managing Environmental impacts of Recreation and Tourism in Rainforests of the Wet Tropics of Queensland World Heritage Area*. Geographical Research 43(2), 140-151.

Turton, S.M., Kluck, T., Day, T.J. (2000). *Ecological impacts of recreation along walking tracks. In Bentrupperbäumer, J.M. and Reser, Impacts of Visitation and Use in the Wet Tropics of Queensland World Heritage Area, Stage 2*. Wet Tropics Management Authority and Rainforest CRC. Cairns, 135-142.

Veldman, J.W., Putz, F.E. (2010). *Long-distance dispersal of invasive grasses by logging vehicles in a tropical dry forest* . Biotropica 42, 697-703.

Wace, N. (1977). *Assessment of dispersal of plant species: The car-borne flora in Canberra* . Proceedings Ecological Society of Australia 10, 167-186.

Webber, P (2007). *Managing mountain biking, IMBA's guide to providing great riding*. International Mountain Bicycling Association, Boulder, USA.

Whinam, J., Chilcott, N., Bergstrom, M. (2005). *Subantarctic hitchhikers: expeditioners as vectors for the introduction of alien organisms*. Biological Conservation 121, 207-219.

Wichmann, M.C., Alexander, M.J., Soons, M.B., Galsworthy, S., Dunne, L., Gould, R., Fairfax, C., Niggemann, M., Hails, R.S., Bullock, J.M. (2009). *Human-mediated dispersal of seeds over long distances*. Proc. R. Soc. B 276, 523-532.

Willson, M. (1993). *Dispersal mode, seed shadows, and colonization patterns*. Vegetatio 107/108, 261-280.

Wilson, R.F., Turton, S.M., Bentrupperbaumer, J.M., Reser, J.P. (2004). *Visitor Monitoring System for the Wet Tropics World Heritage Area, Volume: Case Studies-Biophysical Assessment*. Wet Tropics Management Authority and Rainforest CRC, Cairns.

Worboys, G., DeLacy, T., Lockwood, M. (2005). *Protected Area Management: Principles and Practice*. second ed, Cambridge University Press, Cambridge.

Zwaenepoel, A., Roovers, P., Hermy, M. (2006). *Motor vehicles as vectors of plant species from road verges in a suburban environment* . Basic and Applied Ecology 7, 83-95.

Other references

Badische Zeitung, Roederer, J. (2014). Rasant abwärts vom Kybfelsensattel. Issue: 19.5.2014.

Göttinger Tageblatt, Klocke, K. (2014). Wenn Biker sich Bahn brechen. Issue: 30.8.2014.

MAXXIS official website: . http://www.maxxis.com/tires/bicycle/mountain. accessed: 31.8.2014.

Mountain Bike Association of New Zealand. *Mountain Bikers Code*. Via: http://www.nzcycletrail.com/plan -your-ride/biking-etiquette, accessed on 20.9.2014.

Schwarzwälder Bote, anon. (2014). Illegale Mountainbike-Strecken im Visier. Issue: 13.3.2014, http://www.schwarzwaelder-bote.de/inhalt.nordschwarzwald-illegale-mountainbike-strecken-im-visier.95a00bcb-13a6-47af-b202-36b855877fac.html, accessed 31.8.2014.

Appendix

Survey questionnaire

Survey concerning
Mountainbiking as a vector of seed dispersal

This is an anonymous survey. Please try to answer each question honestly and to the best of your knowledge.

1) How many times a month do you usually ride?

2) How long are your rides on avarage? (in Kilometers)

3) How regurlarly do you clean your bike after a ride?

❑ Always ❑ every 2nd - 3rd time ❑ every 4th time or less ❑ Never

4) Which type of landscape does your ride typically lead through? **(multiple answers possible)**

❑ Forest ❑ Grassland ❑ Wetlands ❑ Cropland ❑ Urban areas

❑ Others_______________________________________ (please specify)

5) Please estimate how often the type of landscape changes on a regular ride.

6) Does your ride normally lead you through a Nationalpark, a nature conservation zone or other protected areas? (Maybe even on official pathways ----- not necessarily illegal)

❑ Always ❑ Sometimes ❑ Never ❑ I dont know

7) Which type of path do you mostly ride uphill?

❑ Paved Streets ❑ Forest roads ❑ designated bike-/hikingtrails ❑ Inofficial/selfmade trails

8) Which type of path do you mostly ride downhill?

❑ Paved Streets ❑ Forest roads ❑ designated bike-/hikingtrails ❑ Inofficial/selfmade trails

9) Do you also ride when it rains / shortly after rain ?

❑ Yes ❑ Occasionally ❑ No

10) Where do you ride?

❑ the same region, same route ❑ the same region, different route
❑ different regions within your country ❑ different countries

Thank you for your help!

Primary data I

Run #	Distance	Anthriscus	Sinapis	Pastinaca	Onobrychis	Vicia	Seeds front	Seeds rear	Seeds frame	Seeds total	Tyre combo	Precipitation
1	0	78	56	124	5	1	153	98		252	a	0
2	0	77	36	82	3	0	122	76		198	a	0
3	0	131	19	131	0	0	140	152		292	a	0
4	0	98	60	90	16	1	104	161		265	a	0
5	0	96	19	110	4	4	150	83		233	a	0
6	0	109	61	188	7	1	169	197		366	b	0
7	0	160	54	215	28	1	169	289		459	b	0
8	0	81	74	133	13	0	147	154		301	b	0
9	0	120	49	111	43	4	240	87		327	b	0
10	0	104	60	127	24	3	160	158		318	b	0
11	5	64	40	128	16		144	104	0	248	a	0
12	5	94	60	98	12		164	100	0	264	a	0
13	5	105	21	104	0		162	68	1	231	a	0
14	5	37	24	35	4		68	32	0	100	a	0
15	5	53	29	56	9		75	72	0	147	a	0
16	5	44	60	106	6		84	132	0	216	a	0
17	5	17	9	58	1	4	34	55	1	90	b	0
18	5	15	9	58	1	4	40	47	0	87	b	0
19	5	16	3	25	0	0	27	17	1	45	b	0
20	5	17	8	46	4	3	32	46	0	78	b	0
21	10	12	4	32	0	1	25	24	0	49	b	0
22	10	7	4	33	2	1	12	35	1	48	b	0
23	10	9	6	19	1	0	8	27	1	36	b	0
24	10	8	8	28	4	2	18	32	0	50	b	0
25	10	7	1	31	1	0	17	23	0	40	b	0
26	50	5	0	16	0	0	3	18	1	22	b	0
27	50	4	1	17	0	0	8	14	0	22	b	0
28	50	4	0	18	0	0	11	11	2	24	b	0
29	50	4	1	7	0	0	3	8	0	11	b	0
30	50	0	0	2	0	0	1	1	0	2	b	0
31	10	12	6	20	1	1	22	19	1	42	a	0
32	10	8	2	15	0	2	16	11	0	27	a	0
33	10	17	3	23	1	1	20	24	1	45	a	0
34	10	31	9	38	2	2	42	40	0	82	a	0
35	10	23	12	26	5	1	37	32	1	70	a	0
36	50	10	2	2	0	0	5	9	0	14	a	0
37	50	8	1	8	1	0	11	7	0	18	a	0
38	50	5	3	13	0	0	6	15	0	21	a	0
39	50	8	1	5	0	0	5	9	0	14	a	0
40	50	7	1	2	0	0	5	5	0	10	a	0
41	100	6	1	5	0	0	4	8	0	12	a	0
42	100	3	2	7	0	0	4	8	1	13	a	0
43	100	5	0	2	0	0	3	4	0	7	a	0
44	100	1	0	3	0	1	2	3	1	6	a	0
45	100	4	1	9	0	0	9	5	0	14	a	0
46	5	15	1	26	1	0	19	24	0	43	a	20
47	5	4	1	6	0	0	5	4	2	11	a	20
48	5	6	0	4	1	0	2	9	0	11	a	20
49	5	8	2	15	2	1	11	17	0	28	a	20
50	5	11	0	6	0	0	6	11	0	17	a	20
51	10	12	0	3	1	0	5	10	1	16	a	20
52	10	8	0	9	0	0	8	8	1	17	a	20
53	10	7	0	1	0	0	4	4	0	8	a	20
54	10	2	0	2	0	0	1	2	1	4	a	20
55	10	7	1	4	0	1	3	9	1	13	a	20
56	50	1	0	0	0	0	1	0	0	1	a	20
57	50	0	0	0	0	0	0	0	1	1	a	20
58	50	0	0	0	0	0	0	0	0	0	a	20
59	50	1	1	0	0	0	0	2	0	2	a	20
60	50	0	0	0	0	0	0	0	0	0	a	20
61	20	1	1	1	0	0	1	2	0	3	a	20
62	20	1	1	0	0	0	2	0	0	2	a	20
63	20	2	1	2	0	0	2	3	0	5	a	20
64	20	0	0	0	0	0	0	0	0	0	a	20
65	20	2	0	2	0	0	4	0	0	4	a	20
66	5	7	1	6	0	1	5	10	0	15	b	22
67	5	7	3	6	0	0	11	5	0	16	b	22
68	5	7	2	15	0	0	11	12	1	24	b	22
69	5	6	2	8	0	0	7	9	0	16	b	22
70	5	10	4	10	0	0	18	6	0	24	b	22

Primary data II

Run #	Distance	Anthriscus	Sinapis	Pastinaca	Onobrychis	Vicia	Seeds front	Seeds rear	Seeds frame	Seeds total	Tyre combo	Precipitation
71	10	3	0	10	0	0	7	6	0	13	b	22
72	10	6	1	4	0	0	6	5	0	11	b	22
73	10	5	1	11	0	0	8	8	1	17	b	22
74	10	1	0	7	0	0	1	6	1	8	b	22
75	10	4	0	4	1	0	6	3	0	9	b	22
76	20	3	0	3	1	0	5	1	1	7	b	22
77	20	3	0	2	0	0	4	0	1	5	b	22
78	20	2	1	0	0	0	0	2	1	3	b	22
79	20	3	0	3	0	0	4	1	1	6	b	22
80	20	1	0	2	0	0	3	0	0	3	b	22
81	50	0	0	1	0	0	0	1	0	1	b	22
82	50	0	0	0	0	0	0	0	0	0	b	22
83	50	0	0	0	0	0	0	0	0	0	b	22
84	50	1	0	1	0	0	1	0	1	2	b	22
85	50	3	0	1	0	0	2	0	2	4	b	22
86	0	14	16	46	0	0	40	36		76	b	21
87	0	21	5	30	2	0	28	30		58	b	21
88	0	32	10	51	3	7	63	40		103	b	21
89	0	16	5	31	4	3	33	26		59	b	21
90	0	17	2	31	0	2	32	20		52	b	21
91	0	30	6	43	0	0	29	50		79	a	21
92	0	39	2	17	0	0	22	36		58	a	21
93	0	27	2	19	1	0	25	24		49	a	21
94	0	18	9	30	4	3	32	32		64	a	21
95	0	16	7	32	4	2	33	28		61	a	21
96	20	14	0	4	0	0	12	6	0	18	a	0
97	20	14	2	6	0	0	13	8	1	22	a	0
98	20	20	5	4	0	0	15	14	1	30	a	0
99	20	11	4	11	0	0	11	15	0	26	a	0
100	20	12	8	15	0	0	20	15	1	36	a	0
101	200	0	0	0	0	0	0	0	0	0	a	0
102	200	2	0	0	0	0	0	2	0	2	a	0
103	200	2	0	0	0	0	2	0	1	3	a	0
104	200	2	0	1	0	0	1	2	1	4	a	0
105	200	0	0	0	0	0	0	0	0	0	a	0
106	20	15	4	27	0	0	19	27	0	46	b	0
107	20	7	3	6	0	0	7	9	0	16	b	0
108	20	12	0	22	0	0	20	14	0	34	b	0
109	20	11	5	13	0	0	17	12	0	29	b	0
110	20	3	2	6	2	0	7	4	1	12	b	0
111	100	5	0	2	0	0	4	3	1	8	b	0
112	100	3	0	1	0	0	3	1	1	5	b	0
113	100	5	2	3	0	0	6	4	0	10	b	0
114	100	2	1	5	0	0	5	3	0	8	b	0
115	100	3	0	5	0	0	5	3	0	8	b	0
116	200	0	0	2	0	0	1	1	2	4	b	0
117	200	1	1	3	0	0	0	5	0	5	b	0
118	200	2	0	1	0	0	2	1	0	3	b	0
119	200	2	0	2	0	0	3	1	1	5	b	0
120	200	2	0	3	0	0	0	5	1	6	b	0
121	500	0	0	0	0	0	0	0	0	0	a	0
122	500	0	0	0	0	0	0	0	0	0	a	0
123	500	0	0	0	0	0	0	0	1	1	a	0
124	500	0	0	0	0	0	0	0	0	0	a	0
125	500	0	0	0	0	0	0	0	1	1	a	0
126	500	0	0	0	0	0	0	0	0	1	b	0
127	500	1	0	0	0	0	0	1	0	1	b	0
128	500	0	0	0	0	0	0	0	1	1	b	0
129	500	0	0	0	0	0	0	0	0	0	b	0
130	500	0	0	0	0	0	0	0	0	0	b	0
131	100	0	0	0	0	0	0	0	0	0	b	22
132	100	0	0	0	0	0	0	0	1	1	b	22
133	100	1	0	0	0	0	0	1	0	1	b	22
134	100	0	0	0	0	0	0	0	0	0	b	22
135	100	0	0	0	0	0	0	0	1	1	b	22
136	100	0	0	0	0	0	0	0	0	0	a	22
137	100	0	0	0	0	0	0	0	1	1	a	22
138	100	0	0	0	0	0	0	0	0	0	a	22
139	100	0	0	0	0	0	0	0	0	0	a	22
140	100	0	0	0	0	0	0	0	2	2	a	22

Table 3.1.1.

	Semi-wet		Wet	
	absolute	**% of exposed seed**	**absolute**	**% of exposed seed**
Total	301.1 ±23.4	17.9	65.9 ±5.1	3.9
Pastinaca	131.1 ±13.0	39.6	33 ±3.5	10.0
Anthriscus	105.4 ±8.3	31.9	23 ±2.7	7.0
Sinapis	48.8 ±5.8	14.8	6.4 ±1.4	1.9
Onobrychis	14.3 ±4.3	4.3	1.8 ±0.6	0.5
Vicia	1.5 ±0.5	0.5	1.7 ±0.7	0.5

Table 3.1.2.

Semi-wet conditions	
Model	**ΔAIC**
Single exponential	2.74147455859016
Double exponential	0
Linear	144.973992002937
Wet conditions	
Model	**ΔAIC**
Single exponential	0
Double exponential	2.00708748758734
Linear	115.208996639547

Table 3.1.3.

Glm (seed attachment over distance) for seeds attached to the frame

Semi-wet conditions

AIC: 26.703

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	4.0959117	0.5978232	6.851	0.00101	**
distance	-0.0007586	0.0028733	-0.264	0.80230	

Wet conditions

AIC: 21.31

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	3.852751	0.937531	4.109	0.0261	*
distance	0.009385	0.018369	0.511	0.6446	

Table 3.2.1.

Glm (seed attachment over distance) with seed species as categorical explanatory variable

Semi-wet

Glm with asinh transformed data AIC: 1264.1

```
                   Estimate Std. Error t value Pr(>|t|)
(Intercept)        3.2461586  0.1394625  23.276  < 2e-16 ***
distance          -0.0056884  0.0003734 -15.236  < 2e-16 ***
SpeciesSinapis    -0.9485110  0.1883823  -5.035 7.33e-07 ***
SpeciesPastinaca   0.2120959  0.1883823   1.126    0.261
SpeciesOnobrychis -1.8784262  0.1883823  -9.971  < 2e-16 ***
SpeciesVicia      -2.2281623  0.1921895 -11.594  < 2e-16 ***
```

```
anova
         Df Deviance Resid. Df Resid. Dev
NULL                       393    1259.74
distance  1   338.95       392     920.80
Species   4   370.02       388     550.77
```

Glm with log transformed data AIC: 1212.6

```
                    Estimate Std. Error t value Pr(>|t|)
(Intercept)        2.5261026  0.1306404  19.336  < 2e-16 ***
distance          -0.0046356  0.0003497 -13.255  < 2e-16 ***
SpeciesSinapis    -0.8556661  0.1764656  -4.849  1.8e-06 ***
SpeciesPastinaca   0.2104571  0.1764656   1.193    0.234
SpeciesOnobrychis -1.5987985  0.1764656  -9.060  < 2e-16 ***
SpeciesVicia      -1.9191717  0.1800320 -10.660  < 2e-16 ***
```

```
anova
         Df Deviance Resid. Df Resid. Dev
NULL                       393     985.47
distance  1   225.46       392     760.01
Species   4   276.71       388     483.29
```

wet

Glm with asinh transformed data AIC: 781.48

```
                   Estimate Std. Error t value Pr(>|t|)
(Intercept)        2.318096   0.121911  19.015  < 2e-16 ***
distance          -0.018393   0.001452 -12.669  < 2e-16 ***
SpeciesSinapis    -1.061155   0.160365  -6.617 1.73e-10 ***
SpeciesPastinaca  -0.001704   0.160365  -0.011    0.992
```

```
SpeciesOnobrychis -1.479674   0.160365  -9.227  < 2e-16 ***
SpeciesVicia      -1.554102   0.160365  -9.691  < 2e-16 ***

anova
         Df Deviance Resid. Df Resid. Dev
NULL                       299     493.11
distance  1   123.83       298     369.28
Species   4   142.45       294     226.82
```

Glm with log transformed data AIC: 705.4

```
                   Estimate Std. Error t value Pr(>|t|)
(Intercept)        1.609458   0.107393  14.987  < 2e-16 ***
distance          -0.013876   0.001279 -10.850  < 2e-16 ***
SpeciesSinapis    -0.893454   0.141268  -6.325 9.43e-10 ***
SpeciesPastinaca   0.046735   0.141268   0.331    0.741
SpeciesOnobrychis -1.155187   0.141268  -8.177 8.79e-15 ***
SpeciesVicia      -1.180784   0.141268  -8.358 2.56e-15 ***

anova
         Df Deviance Resid. Df Resid. Dev
NULL                       299     336.69
distance  1   70.474       298     266.21
Species   4   90.195       294     176.02
```

Table 3.2.2.

Glm (seed attachment over distance) with seed weight as explanatory variable

Semi-wet

Glm with asinh transformed data AIC: 1304

```
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.2638342  0.1038481   31.43   <2e-16 ***
distance    -0.0056707  0.0003942  -14.39   <2e-16 ***
weight      -0.0709345  0.0051349  -13.81   <2e-16 ***

anova
         Df Deviance Resid. Df Resid. Dev
NULL                       393    1259.74
distance  1   338.95       392     920.80
weight    1   302.00       391     618.79
```

Glam with log transformed data AIC: 1248.6

```
              Estimate Std. Error t value Pr(>|t|)
```

```
(Intercept)  2.5399541  0.0967968   26.24   <2e-16 ***
distance    -0.0046208  0.0003674  -12.58   <2e-16 ***
weight      -0.0608716  0.0047863  -12.72   <2e-16 ***

anova
         Df Deviance Resid. Df Resid. Dev
NULL                       393     985.47
distance  1   225.46       392     760.01
weight    1   222.40       391     537.61
```

wet

Glm with asinh transformed data AIC: 832.92

```
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  2.125255   0.096556   22.01   <2e-16 ***
distance    -0.018393   0.001590  -11.57   <2e-16 ***
weight      -0.044775   0.004428  -10.11   <2e-16 ***

anova
         Df Deviance Resid. Df Resid. Dev
NULL                       299     493.11
distance  1  123.834       298     369.28
weight    1   94.586       297     274.69
```

Glm with log transformed data AIC: 754.8

```
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  1.448469   0.084767  17.088   <2e-16 ***
distance    -0.013876   0.001396  -9.943   <2e-16 ***
weight      -0.033987   0.003887  -8.744   <2e-16 ***

anova
         Df Deviance Resid. Df Resid. Dev
NULL                       299     336.69
distance  1   70.474       298     266.21
weight    1   54.500       297     211.71
```

Table 3.2.3.

Glm (seed attachment over distance) with seed volume as explanatory variable

Semi-wet

Glm with asinh transformed data AIC: 1371.6

```
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.1045598  0.1163305  26.687   <2e-16 ***
distance    -0.0057592  0.0004294 -13.411   <2e-16 ***
volume      -0.0146882  0.0014756  -9.954   <2e-16 ***

anova
         Df Deviance Resid. Df Resid. Dev
NULL                       393    1259.74
distance  1   338.95       392     920.80
volume    1   186.17       391     734.63
```

Glm with log transformed data AIC: 1308.7

```
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  2.3949345  0.1074056  22.298   <2e-16 ***
distance    -0.0046968  0.0003965 -11.846   <2e-16 ***
volume      -0.0124511  0.0013624  -9.139   <2e-16 ***

anova
         Df Deviance Resid. Df Resid. Dev
NULL                       393     985.47
distance  1   225.46       392     760.01
volume    1   133.78       391     626.23
```

wet

Glm with asinh transformed data AIC: 859.34

```
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  2.063584   0.103149  20.006  < 2e-16 ***
distance    -0.018393   0.001661 -11.073  < 2e-16 ***
volume      -0.010345   0.001249  -8.283 4.15e-15 ***

anova
         Df Deviance Resid. Df Resid. Dev
NULL                       299     493.11
distance  1  123.834       298     369.28
volume    1   69.299       297     299.98
```

Glm with log transformed data AIC: 773.18

```
             Estimate Std. Error t value Pr(>|t|)
```

```
(Intercept)  1.408017   0.089350  15.758  < 2e-16 ***
distance    -0.013876   0.001439  -9.643  < 2e-16 ***
volume      -0.007969   0.001082  -7.366 1.74e-12 ***

anova
         Df Deviance Resid. Df Resid. Dev
NULL                       299     336.69
distance  1   70.474       298     266.21
volume    1   41.123       297     225.09
```

Table 3.3.1.

Glm for initial attachment (dependent variable) and weather condition (independent variable)

```
Overall                                                    AIC: 219.83
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   301.10      16.91  17.802 7.11e-13 ***
precip.      -235.20      23.92  -9.833 1.16e-08 ***

Pastinaca                                                  AIC: 196.91
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  131.100      9.536  13.748 5.49e-11 ***
precip.      -98.100     13.486  -7.274 9.24e-07 ***

Anthriscus                                                 AIC: 179.36
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  105.400      6.149  17.140 1.36e-12 ***
precip.      -82.400      8.696  -9.475 2.03e-08 ***

Sinapis                                                    AIC: 164.44
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   48.800      4.235   11.52 9.66e-10 ***
precip.      -42.400      5.989   -7.08 1.33e-06 ***

Onobrychis                                                 AIC: 151.82
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   14.300      3.089   4.629 0.000208 ***
precip.      -12.500      4.369  -2.861 0.010377 *

Vicia                                                      AIC: 87.409
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   1.5000     0.6173   2.430   0.0258 *
precip.       0.2000     0.8731   0.229   0.8214
```

Table 3.3.2.

Glm (seed attachment over distance) with weather condition (precip.) as categorical explanatory variable

Overall

Glm with asinh transformed data AIC: 457.82

```
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.7782365  0.1647821   29.00  < 2e-16 ***
distance    -0.0109610  0.0008366  -13.10  < 2e-16 ***
precip.     -1.9923545  0.2186932   -9.11  8.9e-16 ***

anova
         Df Deviance Resid. Df Resid. Dev
NULL                       139     501.79
distance  1   174.66       138     327.13
precip.   1   123.42       137     203.72
```

Glm with log transformed data AIC: 445.05

```
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.0605800  0.1574400  25.791  < 2e-16 ***
distance    -0.0103251  0.0007994 -12.917  < 2e-16 ***
precip.     -1.9183710  0.2089489  -9.181 5.92e-16 ***

anova
         Df Deviance Resid. Df Resid. Dev
NULL                       139     453.52
distance  1   153.13       138     300.39
precip.   1   114.42       137     185.97
```

Pastinaca

Glm with asinh transformed data AIC: 459.78

```
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.9439155  0.1659431  23.767  < 2e-16 ***
distance    -0.0100785  0.0008425 -11.962  < 2e-16 ***
precip.     -1.8838898  0.2202340  -8.554 2.11e-14 ***
```

Glm with log transformed data AIC: 447.36

```
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.185548   0.158741  20.068  < 2e-16 ***
distance    -0.008694   0.000806 -10.787  < 2e-16 ***
precip.     -1.689112   0.210675  -8.018 4.26e-13 ***
```

Anthriscus

Glm with asinh transformed data AIC: 431.34

```
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.6265853  0.1499148  24.191  < 2e-16 ***
distance    -0.0091272  0.0007611 -11.991  < 2e-16 ***
precip.     -1.5941864  0.1989617  -8.013 4.38e-13 ***
```

Glm with log transformed data AIC: 418.89

```
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  2.877244   0.143395  20.065  < 2e-16 ***
distance    -0.007810   0.000728 -10.727  < 2e-16 ***
precip.     -1.454815   0.190309  -7.645  3.3e-12 ***
```

Sinapis

Glm with asinh transformed data AIC: 444.58

```
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  2.397669   0.157177  15.255  < 2e-16 ***
distance    -0.006593   0.000798  -8.261 1.10e-13 ***
precip.     -1.504579   0.208599  -7.213 3.38e-11 ***
```

Glm with log transformed data AIC: 417.35

```
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  1.7296267  0.1426105  12.128  < 2e-16 ***
distance    -0.0051706  0.0007241  -7.141 4.94e-11 ***
precip.     -1.2820241  0.1892678  -6.774 3.40e-10 ***
```

Onobrychis

Glm with asinh transformed data AIC: 379.77

```
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  1.0881222  0.1246964   8.726 7.98e-15 ***
distance    -0.0031608  0.0006331  -4.993 1.78e-06 ***
precip.     -0.7193623  0.1654928  -4.347 2.67e-05 ***
```

Glm with log transformed data AIC: 319.22

```
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  0.659103   0.100449   6.562 1.01e-09 ***
distance    -0.002211   0.000510  -4.336 2.80e-05 ***
precip.     -0.564484   0.133313  -4.234 4.18e-05 ***
```

Vicia

Glm with asinh transformed data AIC: 234.73

```
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  0.5223779  0.0815252   6.408 2.45e-09 ***
```

```
distance    -0.0015301  0.0003981  -3.844 0.000188 ***
precip.     -0.2783261  0.1051310  -2.647 0.009106 **

Glm with log transformed data                                          AIC: 123.04
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  0.1440369  0.0537399   2.680  0.00830 **
distance    -0.0007519  0.0002624  -2.865  0.00486 **
precip.     -0.1200087  0.0693004  -1.732  0.08568 .
```

Table 3.3.3.

Glm (seed attachment over distance) for seeds attached to the frame with weather condition as explanatory variable

```
                                                                    AIC: 44.54
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.0557446  0.6059537   6.693 8.92e-05 ***
distance    -0.0004409  0.0028831  -0.153    0.882
pwet         0.1605694  0.7929861   0.202    0.844
```

Table 3.4.

Glm (seed attachment over distance) with tyre model as categorical explanatory variable

```
Front tyre in semi-wet conditions
Glm with asinh transformed data                                        AIC: 261.03
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.9656422  0.2050944  19.336   <2e-16 ***
distance    -0.0091688  0.0008377 -10.945   <2e-16 ***
Tyre        -0.2327835  0.2686246  -0.867    0.389

Glm with log transformed data                                          AIC: 260.68
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.2596507  0.2046421  15.929  < 2e-16 ***
distance    -0.0080797  0.0008359  -9.666 6.29e-15 ***
Tyre        -0.2746486  0.2680321  -1.025    0.309

Front tyre in wet conditions
Glm with asinh transformed data                                        AIC: 169.65
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  2.724697   0.205494  13.259  < 2e-16 ***
distance    -0.034623   0.003529  -9.811 7.52e-14 ***
Tyre         0.284561   0.246531   1.154    0.253
```

Glm with log transformed data AIC: 165.95

```
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  1.997438   0.199259  10.024 3.44e-14 ***
distance    -0.028059   0.003422  -8.200 3.20e-11 ***
Tyre         0.274449   0.239051   1.148    0.256
```

Rear tyre in semi-wet conditions

Glm with asinh transformation AIC: 249.34

```
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.9024695  0.1991047  19.600   <2e-16 ***
distance    -0.0090686  0.0007784 -11.650   <2e-16 ***
Tyre         0.0169290  0.2493645   0.068    0.946
```

Glm with log transformed data AIC: 252.61

```
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.1201868  0.2032138   15.35  < 2e-16 ***
distance    -0.0080391  0.0007945  -10.12 8.59e-16 ***
Tyre         0.1042786  0.2545109    0.41    0.683
```

Reat tyre in wet conditions

Glm with asinh transformed data AIC: 183.97

```
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  2.757021   0.231549  11.907  < 2e-16 ***
distance    -0.034141   0.003976  -8.586 7.37e-12 ***
Tyre         0.073346   0.277789   0.264    0.793
```

Glm with log transformed data AIC: 171.42

```
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  2.054851   0.208549   9.853 6.45e-14 ***
distance    -0.028456   0.003581  -7.946 8.46e-11 ***
Tyre         0.133987   0.250196   0.536    0.594
```

Summary in German language

Der unbeabsichtigte Samentransport durch Menschen kann weitreichende Folgen haben. Die unkontrollierte Verbreitung von nicht-autochtonen Arten kann beispielsweise zu ökologischen Invasionen führen oder diese begünstigen. Dies muss auch bei Sport und anderen Freizeitaktivitäten in der Natur berücksichtigt werden. Oft sind diese in Gebieten, in denen Flora und Fauna als schützenswert gelten, z.B. in Naturschutzgebieten oder Nationalparks, erlaubt, werden teilweise ausdrücklich gefördert und erfreuen sich daher großer Beliebtheit. Bisher gerieten Wanderer, Autos und auch Nutztiere in den Fokus der Forschung und wurden bezüglich ihres Potentials der Samenausbreitung untersucht. Entsprechende Forschungen zu Mountainbikes gab es bisher nicht. Dabei lässt der Sport seit einigen Jahrzehnten weltweit regen Zuwachs verzeichnen.

Diese Studie untersucht das allgemeine Vermögen von Mountainbikes, Pflanzensamen zu verbreiten. Zu diesem Zweck wurde ein manipulatives Experiment entwickelt. Farblich markierte Pflanzensamen von fünf Arten (*Pastinaca sativa, Onobrychis viciifolia, Vicia villosa, Sinapis alba, Anthriscus sylvestris)* wurden auf einem Waldpfad nahe Freiburg i. Br. ausgelegt. Ein darüber fahrendes Mountainbike legte bestimmte Strecken zurück, nach denen die anhaftenden Samen gezählt wurden. Dies geschah sowohl unter wechselfeuchten als auch nassen Bedingungen, nachdem eine Pilot-Studie ergab, dass der Samentransport bei gänzlich trockenen Bedingungen unbedeutend gering ausfällt. Zusätzlich wurde die Einflussnahme zweier verschiedener Reifenmodelle auf die Versuchsergebnissee getestet.

Es zeigte sich, dass bis zu 39,6% der vom Mountainbike überfahrenen Samen aufgenommen wurden. Einzelne Samen wurden bis zu 500m transportiert. Die Zahl der an den Reifen haftenden Samen verringerte sich mit der zurückgelegten Distanz; ein *single exponential* und ein *double exponential model* beschrieben diesen Zusammenhang am besten. Allerdings wurden auch Samen am Fahrradrahmen und anderen Teilen des Fahrrads gefunden, bei welchen keine Verringerung mit der zurückgelegten Distanz festgestellt werden konnte. Die Ergebnisse zeigen signifikante Unterschiede bei den Samen verschiedener Arten. Kleine Samen mit geringem Gewicht wurden in deutlich größeren Mengen über größere Distanzen transportiert. Die wechselfeuchten Bedingungen erwiesen sich gegenüber den komplett nassen Bedingungen als förderlich für den Samentransport. Bei den verschiedenen Reifenmodellen war jedoch kein signifikanter Unterschied erkennbar.

Zudem ergab eine Umfrage unter Mountainbikern im Schwarzwald, dass eine vielfältige Infrastruktur genutzt wird. Oft werden verschiedene Landschaftstypen durchquert und auch in Schutzgebieten wird häufig gefahren.

Mountainbikes haben durchaus das Potential als Samenvektoren zu fungieren. Allerdings ist dieses Potential von den umliegenden Bedingungen und von den Eigenschaften der betreffenden Samen abhängig. Der Hauptteil der anhaftenden Samen wird nur über kurze Strecken transportiert. Bei am Fahrradrahmen haftenden Samen sowie bei Samen, die an Kleidung bzw. Ausrüstung der Fahrenden haften, sind hingegen größere Transportdistanzen wahrscheinlich.

Um die Umweltauswirkungen des Mountainbikings besser kontrollieren zu können, empfiehlt es sich, die Aktivitäten auf eigens dafür konzipierte Wege zu konzentrieren. Weitere Forschung sollte sich damit auseinandersetzen, wie sich verschiedene Geschwindigkeit auf das Vektorpotential auswirken. Außerdem sollten weitere Sameneigenschaften hinsichtlich ihrer Förderlichkeit zur Verbreitung durch Mountainbikes verglichen werden. Nicht zuletzt aufgrund der wachsenden Popularität der Sportart, sollte in Zukunft das Vektorpotential von Mountainbikes im naturschutzfachlichen Kontext mehr Berücksichtigung finden.

Affidavit

(Eidesstattliche Erklärung)

Hiermit versichere ich, dass

1) ich die eingereichte Bachelorarbeit eigenständig verfasst habe,

2) ich keine anderen als die angegebenen Quellen und Hilfsmittel benutzt und alle wörtlich oder sinngemäß aus anderen Werken übernommenen Inhalte als solche kenntlich gemacht habe,

3) die eingereichte Bachelorarbeit weder vollständig noch in wesentlichen Teilen Gegenstand eines anderen Prüfungsverfahrens ist oder war und

4) die elektronische Version der eingereichten Bachelorarbeit in Inhalt und Formatierung mit den auf Papier ausgedruckten Exemplaren übereinstimmt.

Ort, Datum ______________________________ Unterschrift ______________________________