Off-road driving and the ecosystem: An analysis of the impacts on landscape functionality

Item Type	Book chapter
Authors	Stevens, Mirre
Citation	Stevens, M. (2019). Off-road driving and the ecosystem: An analysis of the impacts on landscape functionality. In Mijts, E. & Ballantyne, J. (eds.). (2019). UAUCU Student Research Exchange - Collected Papers 2019. Aruba. University of Aruba. 35-61.
Publisher	University of Aruba/University College Utrecht
Journal	UAUCU Student Research Exchange – Collected Papers 2019
Download date	2026-06-10 07:00:09
Link to Item	https://hdl.handle.net/20.500.14473/1762

Seas and Sustainable Development: Implementation and Follow-up to Rio + 20, (April), 1–7.

- Lee, S. Y., Primavera, J. H., Dahdouh-Guebas, F., Mckee, K., Bosire, J. O., Cannicci, S., … Record, S. (2014). Ecological role and services of tropical mangrove ecosystems: A reassessment. Global Ecology and Biogeography, 23(7), 726–743. https://doi.org/10.1111/geb.12155
- Meteorological Department Curacao. (2017). Hurricanes and Tropical Storms in the Dutch Caribbean. Retrieved from http://www.meteo.cw/Data_www/pdf/pub/Hurricanes and Tropical Storms DC.pdf
- Ostrom, E. (2007). A General Framework for Analyzing Sustainability of Social-Ecological Systems. 325(June), 1–53.
- Parke Nacional Arikok. (2017). A management plan for Spaans Lagoen Aruba. (November).
- Polaszek, T., Lacle, F., Van Beukering, P., & Wolfs, E. (2018). The Economics of Ecosystems and Biodiversity, Aruba.
- Polman, N., Reinhard, S., & Kuhlman, T. (2016). Governance of ecosystem services on small islands: three contrasting cases for St. Eustatius in the Dutch Caribbean. 11(1), 265–284.
- Ramsar. (1980). Het Spaans Lagoen. Retrieved from https://rsis.ramsar.org/ris/198
- Ridderstaat, J., Oduber, M., Croes, R., Nijkamp, P., & Martens, P. (2014). Impacts of seasonal patterns of climate on recurrent fluctuations in tourism demand: Evidence from Aruba. Tourism Management, 41, 245–256. https://doi.org/10.1016/j.tourman.2013.09.005
- Ridderstraat, J. R. (2008). LAGO story: the compelling story of an oil company on the island of Aruba. Oranjestad: Editorial Charuba.
- Susan, B., Fortuna, S., Broadhead, J., & Leslie, R. (2006). Coastal protection in the aftermath of the Indian Ocean tsunami: What role for forests and trees ? Proceedings of the Regional Technical Workshop, 236.
- Twilley, R. R., & Chen, R. (1998). A gap dynamic model of mangrove forest development along gradients of soil salinity and nutrient resources. Journal of Ecology, (86), 37–58.
- United Nations Development Program. (2014). poverty eradication Sustainable consumption and production Sustainable cities and settlements peaceful and non-violent societies, capable institutions health and population dynamics Employment and decent work for all. (82), 20–23. Retrieved from http://www.igbp.net/download/18.62dc35801456272b46d51/1399290813740/NL82-SDGs.pdf
- United Nations. (2015). Sustainable Development Goals. Retrieved from https://www.un.org/sustainabledevelopment/sustainable-development-goals/
- Van der Perk, J. P. (2002). Towards sustainable development of Aruba: Indicators for Ecological Quality. Development of an environmental assessment method for Aruba. VROM Aruba.
- van Zanten, B., Laclé, F., van Duren, S., Soberon, V., & van Beukering, P. (2018). The Value Natural Capital for the Tourism Industry of Aruba. (January).
- Wolfs, E., Laclé, F., Bubalo, M., van Beukering, P., & Pols, R. (2017). Cultural Ecosystem Services (CES) for Local Community in Aruba.
- Zhang, K., Liu, H., Li, Y., Xu, H., Shen, J., Rhome, J., & Smith, T. J. (2012). The role of mangroves in attenuating storm surges. Estuarine, Coastal and Shelf Science, 102–103, 11–23. https://doi.org/10.1016/j.ecss.2012.02.021

Mirre Stevens, University College Utrecht

Here comes the sun, and I say “it's all right”

If you would have asked me at the start of my bachelor's thesis whether I would've successfully completed an independent research project on Aruba, I probably would have laughed at you. I did not think myself capable of this, and honestly there were moments throughout entire process where I considered quitting. As you're reading this right now, I didn't, and I'm so very glad I didn't. Instead I asked for help, pushed through, gave up a little, and learnt some valuable lessons along the way.

The thing people tell you about research in advance, is that it's going to end up changing in practice, and your expectations are going to be changed. That's a fundamental part of the difference between theory and practice, and I think that a lesson I learnt both from the iterative learning process of doing an independent research project for my bachelor thesis, but also majorly from living the island life on Aruba for almost three months.

The preparatory course, and over 300 articles of literature I read in preparation for this did not at all prepare me for arriving on Aruba, but I suppose that's also an inherent component of doing community based research that didn't actually click with me until I was actually here. As the researcher, you're not the expert, you're a person with a passion for answering a question, and this project allowed me to do so with the collaboration and support of a whole book full of brilliant minds.

I'd like to thank every single person I shared even a couple of minutes of conversation with, from the people on the bus to San Nicholas, the locals and tourists alike hiking through Parke Arikok, the students at UA sharing their tablespace with me. I'd specifically like to mention Duan and Olinda from StimAruba for inviting me on hikes and walking tours to see Aruba, and sharing their wonderful knowledge of the vegetation. I'd like to thank Giancarlo Nunes from Parke Arikok for collaborating with me on this project, joining me in the field, and sharing his knowledge. I'd like to thank Maarten Eppinga for approving my initial proposal and introducing me to my supervisor, Angeles Garcia-Mayor, who has been a lifesaver and a fountain of passion and knowledge. Thanks to Tobia for inviting me along on the AFY fieldtrips and getting my first hand-on experiences with research on the island. I'd like to thank Annemieke, Tatiana, and Marretje for listening to my rants and rambles about experimental design, and lending a helpful perspective. I'd like to thank my family and friends back home who gave me buckets of support in making this decision. I'd like to thank the rest of the UAUCU girls for their continued support, laughter, banter, singing and studying sessions. Last but not least, I'd like to thank Eric Mijts and Jocelyn Ballantyne for their continued support from the start of the preparatory class, and for making this programme a possibility.

I had an amazing time, watching sunrises and sunsets on all the coasts and beaches of the island. Getting sunburnt at each and every single one of them. Exploring all of the small food places, supermarket, fruiterias and batido stands. I probably have some hearing damage from blasting the radio and vast collection of playlists that we've accumulated over our time here. I've got an entire collection full of photographs that I'm going to spend weeks editing and cleaning up when I get back home, sending them around with funny captions and memories. That, and writing up the more extensive and final version of my thesis, because that also needs to be done.

Off-road driving and the ecosystem: An analysis of the impacts on landscape functionality.

Mirre Stevens

1. Introduction

Historically, Aruba's terrestrial arid ecosystems have been perceived as barren and useless, so much so as to earn Aruba one of its first labels: "isla inútil"(Industries, n.d.). Nothing could be less true, arid ecosystems have a wide range of ecosystem services: they provide – erosion control and soil retention, water regulation, habitat for terrestrial fauna, recreational value, economic value as touristic attraction among others (Polaszek et al., 2018; Schilstra et al., 2003; Wolfs et al., 2017). However, all of these services are under threat due to ecosystem degradation and biodiversity loss (Oosterhuis, 2016). Climate change and other anthropogenic stressors – among which deforestation, grazing and off-road driving – are influencing vegetation cover and ecosystem degradation (Asner et al. 2004; Bilotta et al., 2007; Buckley, 2004).

Globally, the pressure of off-road driving on the ecosystem has increased drastically as the activity has gained popularity as a recreational activity (Goossens & Buck, 2014). With the Aruban landscape fitting the stereotypical outback and the island receiving over 1.6 million tourists annually (CBS, n.d.), off-roading has become one of the main tourist attractions (Vogel, 2017). With an increase in the pressure, there is an urgent need to understand the effects of off-road driving on the vegetation, and to work towards managing and limiting these detrimental effect in a sustainable manner.

Therefore, this research aims to look into the impacts of off-road driving on landscape functionality of the Aruban xeric shrubland vegetation, through asking the following main research question:

What are the impacts of off-road vehicle traffic on landscape functionality of the Aruban xeric shrubland ecosystem?

This will be accomplished by answering the following sub-questions:

1. *What is the extent of off-road vehicle usage and traffic on Aruba?*
2. *Is there a statistically significant difference in LFA (Landscape Function Analysis) values between areas exposed to off-road traffic and control areas?*
3. *How big is the difference in landscape functionality between roadside and non-roadside locations?*
4. *How do the soil quality, water infiltration, nutrient cycling LFA index values compare between research conditions?*
5. *How does the vegetation cover compare between research conditions?*
6. *Do the LFA index values differ within patch types between research conditions?*

This paper will first provide a literature review. Second, it will outline further details on the study area. Then, it will explain the material and methods and, finally, it will present the preliminary data and analysis thereof.

This research project was conducted with a community-based approach, which means stakeholders were involved with the gathering of relevant data, decision-making on main research objectives and research areas, and will be involved with further analysis and conclusions.

2.Theoretical Background/Literature Review

First, this literature review examines the basics of arid ecosystems by looking at the definitions and terminology involved, and describing the patch formations and dynamics. Second, ecosystem degradation and anthropogenic factors influencing this are discussed with a particular focus on grazing and off-road driving. Then, the Aruban context is described.

2.1 Arid Ecosystems and Patch Dynamics

Arid ecosystems are ecosystems that are characterised by their low moisture levels. Globally, arid ecosystems vary greatly in terms of the amount of rainfall they receive, but through evaporation exceeding this rainfall they are generally moisture deficient (WWF, n.d.). The characterized vegetation of these ecosystems is woody-stemmed shrubs. Although there is a diverse spread of flora and fauna species, most of which are adapted to this low water availability and often have remarkable evolutionary adaptations to minimize water loss (EPG, n.d.-a). Two examples of arid ecosystems are xeric shrublands (EPG, n.d.-a; WWF, n.d.) and tropical dry forests (EPG, n.d.-b; Fajardo et al., 2012; WWF, n.d.). Their global distributions are shown in Figure 1 and Figure 2, respectively.

Figure 1: Distribution of xeric shrubland on the earth (source Ecology Pocket Guide &TEOW)

Figure 2: Distribution of tropical dry boreal forests on the earth (Source pocket ecology & TEOW).

According to the WWF (WWF, n.d.) xeric shrubland are categorised with the desert biome type, due to their similar arid and moisture deficient conditions but xeric shrublands also have similarities with the tropical dry forest ecosystems, a semi-arid ecosystem with rainfall periods but long dry seasons, resulting in overall moisture deficiency(WWF, n.d.). Due to these differences in water availability (through retention capacity or rainfall), tropical dry forests are able to support larger flora but both remain less productive compared to rainforests and wetter ecosystems (Fajardo et al., 2012)

In these low production ecosystems many species track seasonally variable and patchy resources, and therefore, require larger natural landscapes to persist (WWF, n.d.). The water sources for the system, as well as the riparian habitats, in particular, are critical for the survival of many species(World Wildlife Fund, n.d.).

2.1.1 Patch Mosaic Distribution

In ecosystems that are strongly water-limited, plant cover is usually less than 60% and not continuous (Aguiar & Sala, 1999). Instead, the vegetation in a lot of arid ecosystems is distributed heterogeneously but semi-ordered in a pattern of highly vegetated areas and low plant cover areas, called the two-phase mosaic (Aguiar et al., 1996). The areas with high plant cover are called vegetated patches, and the low cover areas are often called the low-cover matrix. Examples of these non-continuous spatial distributions are shown in Figure 3. This two-phase mosaic arrangement affects several of the ecosystem processes, from abiotic processes like water dynamics and nutrient cycling, to biotic interactions like competition and seed dispersal (Aguiar & Sala, 1999).

The two-phase patch mosaic distribution essentially causes a concentration of resources into these high-cover patches and a scarcity of resources in the low-cover matrix. This heterogeneous spread of resources has implications for the productivity and diversity of an arid ecosystem (Noy-Meir, 1973, 1981).

An empirical study (Sala et al., 1988) indicated a linear relation between annual precipitation and production. This relation indicates that there is a precipitation threshold below which there should be no production. This “ineffective precipitation” would, in the case of homogeneously distributed vegetation, lead to no production. However, the heterogeneous distribution allows a shifting of the effectiveness of the scarce precipitation, i.e. water levels that would not lead to production in homogenous distribution do lead to production in heterogeneous, due to patching. This is because water redistribution in patch ecosystems determines new resource statuses in which the low-cover matrix area is a source of water for the high-cover sink patches (Aguiar & Sala, 1999). It leads to the matrix being much drier and poorer in nutrients and resources than average, whereas the vegetated patched become richer with higher concentrations of nutrients, water and other resources. This increased concentration in the sink patch then becomes above the resource threshold needed for production, and the source patches, which were already below the threshold, do go further below the threshold but production remains zero still.

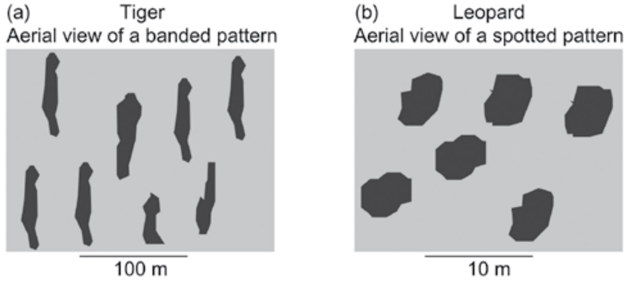


Figure 3: Two types of pattern shapes (Aguiar & Sala, 1999)

2.1.2 The Patch Formation Process

There are multiple patch patterns, though two of the more frequent and recognizable pattern distributions are called the tiger and leopard patterns (Aguiar & Sala, 1999) after the similarity between the patch sketch pattern and the fur patterns of these creatures. The tiger pattern is banded patches of a more rectangular elongated shape (Figure 3a) with the leopard pattern being a more polka dot spotted pattern with irregular shapes (Figure 3b). There are two similar but different development mechanisms at play in the formation of these patches both illustrated in Figure 4.

In the tiger pattern formation process, illustrated by the Chihuahuan desert patch example in Figure 4a, there is an upslope vegetation growth movement combined countering the downslope water and run-off. The patch has vegetation in the building and growing phase on the upslope side and vegetation in the degenerative phase on downslope side. This leads to a general upslope vegetation movement (Aguiar & Sala, 1999). The building phase of new vegetation is on the upslope side of the patch as the downslope water direction and consequent resource transport means the nutrient concentration is highest there, which is an optimal condition for new growth. Whereas the downslope side is the most nutrient depleted, as “use for production” is higher than delivery from source inter patch. In this dynamic system the main vector of movement and transport is run-off and the water direction. The water direction is determined almost entirely by the slope gradient, as water is moved by gravitational pull. This means that this pattern and movement are mostly directed by the slope of the landscape.

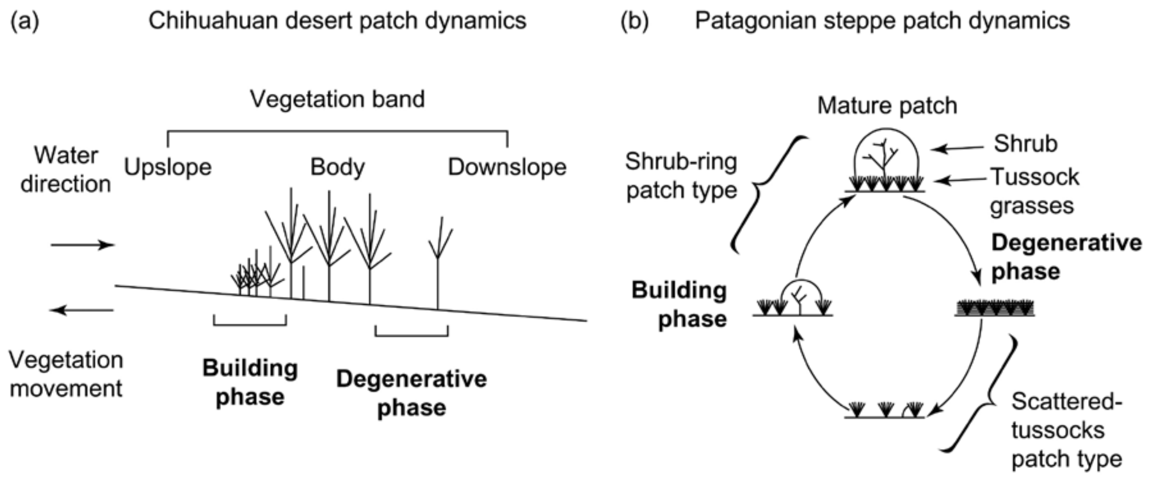


Figure 4: Illustration of the two patch dynamics explained by (Aguiar & Sala, 1999)

The patch dynamics for spotted more irregular vegetation patches are illustrated by the Patagonian steppe example in Figure 4b. The main nutrient movement here is due to a different movement vector, namely, transportation by wind and animals (Aguiar & Sala, 1999). The transportation vectors for these methods of transport are not as unidirectional as the slope vector in the case where the main vehicle is water. Wind direction can have a main general vector of movement, but even then, there are fluctuations, and animal transport is multidirectional (Aguiar & Sala, 1999), as such resource movement more irregularly changes the patches. In this situation, the building phase occurs anywhere in the low-cover matrix, and once a singular shrub has been established the start of a sink is created as resources moved by the wind get "stuck" forming a neighborhood with higher resource concentrations as well as aerial protection that promotes subsequent seed accumulation and seedling establishment. A small patch can thereby grow into a mature patch, until the phase where the patches' internal competition for resources outweighs the benefit of nutrient accumulation and the patch enters the degenerative phase. In the degenerative phase, the shrub dies due to the increasing competition, and this decrease in shrub presence decreases the sinking effect of the patch leading to an increase in grass mortality, which in turn leads to a further thinning and dying of vegetation in the patch. What remains are a scattering of individual shrubs within a larger inter patch matrix, allowing the process to begin again if there is enough nutrient accumulation (Aguiar & Sala, 1999).

2.2 Degradation and Anthropogenic Factors

Throughout recorded history major changes have occurred to arid ecosystems. Vegetative loss, increased soil erosion, reduced productivity, and loss of native species, to name a few (Glendening, 1952; Mabbutt & Floret, 1980). This ecosystem degradation is attributed to direct human activities and climate change, both of which are anthropogenic factors (Brown et al., 1997).

The largest stressor is climate change, through direct climate change and indirect influences over other stressors (J. H. Brown et al., 1997). Climate change leads to changes in precipitation levels and precipitation extremities, often resulting in either lower annual rainfall or more extreme annual rainfall. Water is the most limiting resource in arid ecosystem; as such changes in these precipitation patterns (small volume differences or differences in precipitation patterns) may be expected to have substantial effects on the ecosystem (J. H. Brown et al., 1997).

The schematic in Figure 5 shows the positive-feedback loop of some degradations and stressors relevant to vegetation cover, where vegetation loss results in changes in solar radiation (Albedo), surface roughness, moisture loss through evapotranspiration, dust levels in the atmosphere, which contributes to climate change and decreases in precipitation. These then further increase the loss of vegetation cover, strengthening the cycle (D'Odorico et al., 2013). In addition, the vegetation loss also increases soil erosion and loss of soil fertility, which increases the loss of vegetation cover.

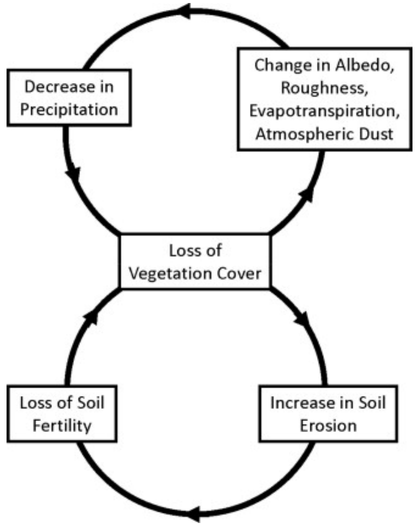


Figure 5: The cyclical positive-feedback loop of land degradation(D'Odorico et al., 2013)

Stressors occur at this global level through climate change, as well as at a more local level through local stressors. The management of stressors upon an ecosystem is a complex combination of building resistance to global stressors and directly managing more local ones (C. J. Brown et al., 2013).

Xeric shrublands are not only sensitive to global stressors like climate change but are also highly sensitive to local stressors like grazing, off-road driving, and other causes of soil disturbances and cover alterations (C. J. Brown et al., 2013; Buckley, 2004; Oosterhuis, 2016; WWF, n.d.).

2.2.1 Grazing

Grazing is cattle and livestock fully or partially living off the land, traditionally through pastures but also often through unregulated free roaming. This grazing pressure can be a stressor on the environment, especially when unregulated, as this often results in overexertion on the ecosystem – called overgrazing. Overgrazing results in desertification and deforestation with consequent changes in the vegetation structure, hydrology, biogeochemistry and bio-atmosphere exchanges of the grazed ecosystem (Asner et al., 2004).

These influences through grazing occur in two main ways, the direct grazing and trampling (Hiernaux et al., 1999).

Grazing is the consumption of plant matter and results in changes in vegetation cover through decreased regeneration of vegetation (Zhou et al., 2010), and composition through selective grazing on specific species, decreasing their numbers disproportionally (Denters, 1979; Zhou et al., 2010). In arid ecosystems, this often results in the development of brush type vegetation of the species not preferred by the grazer (Amiri et al., 2008; Denters, 1979).

Trampling – repeated compression of the dirt - results in compaction of the soil reducing water infiltration

(Mwendera & Saleem, 1997), soil moisture content, and water holding capacity (Stavi et al., 2008). These increases in bulk density and decreases in water infiltration can result in decreased vegetation cover and increased soil vulnerability (Bilotta et al., 2007; Coughenour, 1991).

For arid ecosystems, the consequences of these changes may be significant due to already sensitive environmental balances. Semi-arid regions most commonly receive grazing pressures from goats due to their ability to thrive in tough and arid conditions (Campbell & Donlan, 2005).

2.2.2 Off-road driving

Another anthropogenic stressor on xeric shrublands is off-road driving. This include the driving of motorized vehicles on unpaved roads, dust roads, dirt tracks and outside of pathways (Buckley, 2004). The impact of dirt road and off-road driving on the environment has been recognized for almost 85 years (Bates, 1935), and off-road driving is becoming more popular and widespread as a recreational activity on all continents (Goossens & Buck, 2014; Jones et al., 2016).

Off-road vehicle (ORV) activities cause a series of influences on the land. They increase soil erosion and compaction (Buckley, 2004), increase wind erosion (Goossens & Buck, 2009), cause direct damage to vegetation and soil life (Kutiel et al., 2002; Kutiel, et al., 1999; Lovich, 2002), and indirect damage to vegetation and soil life (Buckley, 2004; Forman & Alexander, 1998; Kutiel et al., 2002, 1999; Lovich, 2002; Vogel, 2017). Off-road vehicles cause dust and air pollution through dust emission (Buckley, 2004; Goossens & Buck, 2009; Vogel, 2017), which impacts soil life (Etyemezian et al., 2004; Kuhns et al., 2010; Nolet & M., 2009; Soukup et al., 2012) and the vegetation (Darley, 1966; Emberson et al., 2001; Farmer, 1993; Sarma, et al., 2017; Sukopp & Werner, 2011; Thakar & Mishra, 2010).

Dust emission is the non-natural wind erosion, often caused by vehicles, and although there are differences between dust emission and wind erosion, they share the three steps in the process. These steps are the detachment, transport, and deposition of the particles in question.

In the detachment step of the off-road vehicle dust emission, the force exerted by the tires upon the soil starts the detachment through loosening particles, either forcing them to become airborne or making them more prone to being detached by wind forces. The stability of the soil, as well as the speed of travel and the tire tread of the off-road vehicle, are determinant factors in the amount of detachment that occurs (Goossens, 2005; Goossens & Buck, 2009, 2014; Vogel, 2017). The more unstable soil being travelled on by rougher tires on vehicles travelling higher speeds result in more detachment.

There are three types of transportation; suspension, saltation and surface creep. Suspension occurs with the finest particles. As they are throwing into the air during detachment they can be carried high and transported over extremely long distances, even thousands of kilometres. It is often the transportation most visible to the naked eye. The most common form of transportation is saltation, where fine soil particles are thrown in the air and increase velocity as they are transported. Surface creep is the movement of heavier particles that cannot be suspended in the wind, that get rolled across the surface and as such creep forward.

Then, there is deposition of the particles. Deposition occurs in highest quantities close to the detachment location, and exponentially decreases as transport distance increases as shown in Figure 6. Within the closest distances the transportation types are suspension and saltation, and when the deposition evens out it is mostly particles falling out of suspension (Goossens & Buck, 2014; Vogel, 2017).

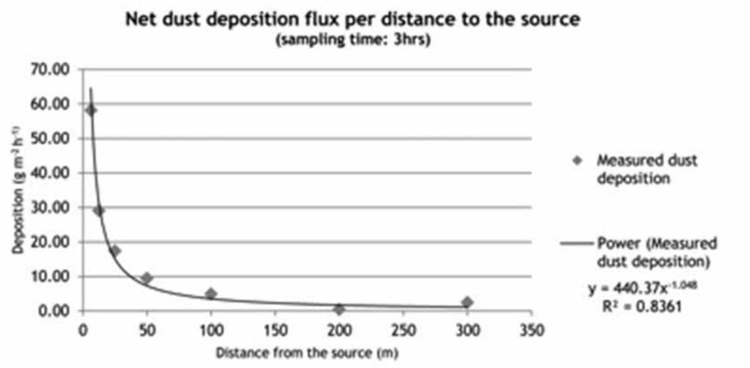


Figure 6: Dust deposition per distance to the source, showing the exponential decrease of dust deposition over transportation distance (Vogel, 2017)

The effects of suspension dust emission are not yet definitely known, but research is indicating that there are effects on human health (Goossens & Buck, 2014) as well as the vegetation. The effects of dust emission on vegetation is through effecting soil quality, which through degradation affects vegetation cover, as well as through several forms of direct damage to the plants (Emberson et al., 2001; Forman & Alexander, 1998; Matsuki et al., 2016; Sarma et al., 2017; Sukopp & Werner, 2011).

3.Aruban Context

3.1 Climate

Aruba is located in the Southern Caribbean near the coast of South America. The small island is 30 kilometres off of the coast of Venezuela, just northwest of the Paraguaná Peninsula. Aruba lies within a semi-arid to arid zone that extends from the Orinoco deltas in eastern Venezuela to northern Columbia (Stoffers, 1956), with an average temperature of 27°C and a range of 24-32° and an average rainfall of 470mm between 1981 and 2010 (Departamento Meteorologico Aruba, 2010). The rainfall is seasonal, and concentrated in the rainy season from late September to February, with the heaviest rain in October and November (Denters, 1979; Departamento Meteorologico Aruba, 2019). The potential evaporation for Aruba is 1600mm/year (N.V. & Sogreah, 1968), but more recent values for Curaçao 2400mm/year (County & Report, 2008) and Bonaire 2600mm/year (Oosterhuis, 2016) may suggest higher potential evaporation values for Aruba. With these specific conditions Aruba is classified as 'BSh' (hot-semi arid) in the Köppen Climate Classifications (Köppen, 1900; Peel, Finlayson, & McMahon, 2007; Rudolf Geiger, 1954).

3.2 Geography

Aruba is located along the transverse fault of the Caribbean tectonic plate moving towards the South American plate, and was created due to volcanic activity along this fault line. The Aruba Lava Formation is the predominant geological rock present on the island, consisting of a basalt type called diabase, schists and volcanic tuffs (Westermann, 1931), with intrusions of tonalite batholith and over layer of reef and eolianite limestone stemming from the Cenozoic age(Oosterhuis, 2016). The limestone forms the characteristic terraces of much of the Aruban North Coast near Alto Vista and Vader Piet, and range from sloping plateaus like the Sero Domi and much flatter terraces.

The extreme north end of Parke Nacional and most of the southern half are limestone plateaus, with the central and northern areas of the park having Aruba Lava Formation at the surface.

3.3 Landscape, soils and hydrology

The geological description – called lithology – of Aruba largely determines the landscape and soils of Aruba. Surveys on the lithology of Aruba have resulted in detailed landscape-soil maps (N.V. & Sogreah, 1968). The three main landscape categories posited reflect the three main geological units, tonalite, Aruba Lava Formation, and limestone. The tonalite are easily weathered, with deep soils with high infiltration capacities, there are hills and shallow valleys with dry-river beds (rooien) and occasional large boulders. The landscape of the Aruba Lava Formation is recognisable by its high hills combined with deeper steep rooien, and the soils are characteristically shallow, with low infiltration capacity and regular rock exposures. The limestone terraces are flat, with rough surfaces with cracks through which the rainwater disappears; there are no rooien as the cracks are an alternative to surface runoff, which produces the valleys. The soils are alkaline and minimal, consisting of the eroded limestone particles, and are not dispersed evenly over the surface but are generally found in the surface cracks.

The ocean determines the Aruban coastline, the trade winds that are dominant from the east/northeast result in rough seas on the north and east coasts of the island, resulting in cliff sides with some beaches where the accumulation of run-off particulates from the rooien have developed sandy inlets. There are some sand dunes and some salty valleys with tidal or seasonal submersion. Examples of these are Boca Daimari, Dos Playa and Boca Prins (Oosterhuis, 2016).

3.4 Hydrology

The hydrologies of the Aruban lithological zones are different. The lava formation rocks have low water permeability and the soils are shallow, as opposed to the limestone where water infiltration can be preserved as groundwater for longer times. These aquifers are a water source for deep-rooted plants during the dry season and as such allows for species with higher water needs and more luxuriant evergreen vegetation to flourish in these areas (Oosterhuis, 2016; Stoffers & Mansour Elassaiss, 1965).

3.5 Vegetation

The vegetation of Aruba and the other leeward Dutch Antilles were first mapped in the early 1950s (Stoffers, 1956) – with the conclusion that at that time little of the original vegetation remained. Historically the Aruban vegetation was much denser tropical dry forest (van Nooren, 2008). The initial dry forests contained significant cover area of Brasilwood, giving Aruba it's early name as the "Brasilwood island", which was cut and exported for a multitude of purposes during the 19th and early 20th century (Alofs, 1997; Versteeg & Ruiz, 1995). In the mid-20th century, further deforestation occurred to make way for gold-mining and Aloe vera plantations (Industries, n.d.). The interest in maintaining the original vegetation of Aruba led to a vegetation survey in the late 1970s (Denters, n.d.), where it was found that a further decrease in vegetation cover, height and proportion of trees had occurred between the 1940's and the 1970's. This trend seems to have occurred in recent years (Oosterhuis, 2016; Willemsen, 2011). This reduction of plant cover has led to increased erosion and soil degradation (N.V. & Sogreah, 1968; Stoffers, 1956) in turn causing less regrowth.

The establishment of National Parke Arikok – covering 18% of Aruba – has safeguarded some Aruban vegetation from further degradation due to direct deforestation, but some anthropogenic pressures on the vegetation remain. The grazing pressure in Parke Arikok was found to be at 1400 goats with reasonably uniform pressure distribution due to the size of the area, and no regions being extremely difficult for goats to access (Veerbeek, 2016). The effects of grazing on the National Parke have been researched in the past (Veerbeek, 2016), and although much more could be done

there, the upcoming extent and impact of off-road driving is still mostly unknown.

3.6 Off-road driving

Another anthropogenic pressure on Aruba is off-road driving. It has been gaining popularity within the Aruban tourism industry, as a considerable source of income through both off-road driving tours as well as individual vehicle rental (Oosterhuis, 2016; Vogel, 2017). Off-road vehicular activities are one of the main tourist attractions, as such high quantities of these vehicles can be seen around the island especially around the tourist high season from November to May (Oosterhuis, 2016). Through personal communications as part of my community-based research approach, concerns were raised about the drastic increase in tour operator and vehicle number quantities on Aruba. Several NGO's, including the Aruba Birdlife Conservation, post photos and queries on Facebook regarding the impacts of these vehicles on the Aruban vegetation and wildlife (Aruba Birdlife Conservation, n.d.) indicating a wider societal worry.

Vogel (2016) mapped the dust roads of Aruba (with the exception of the side-roads in Parke Arikok) as seen in Figure 7. The majority of off-road driving occurs along the North coast of Aruba, with hotspots being the area from California Lighthouse to Daimari, and Vader Piet to Seroe Colorado. However, there are also a lot of unpaved road spread throughout Aruba, in addition to the dust roads within Arikok (which are mapped partially in Figure 8). Also, it must be noted that off-road driving does not only occur on unpaved and dust roads, but also off of roads in vegetated or natural zones often in roadsides or near roads (Buckley, 2004).

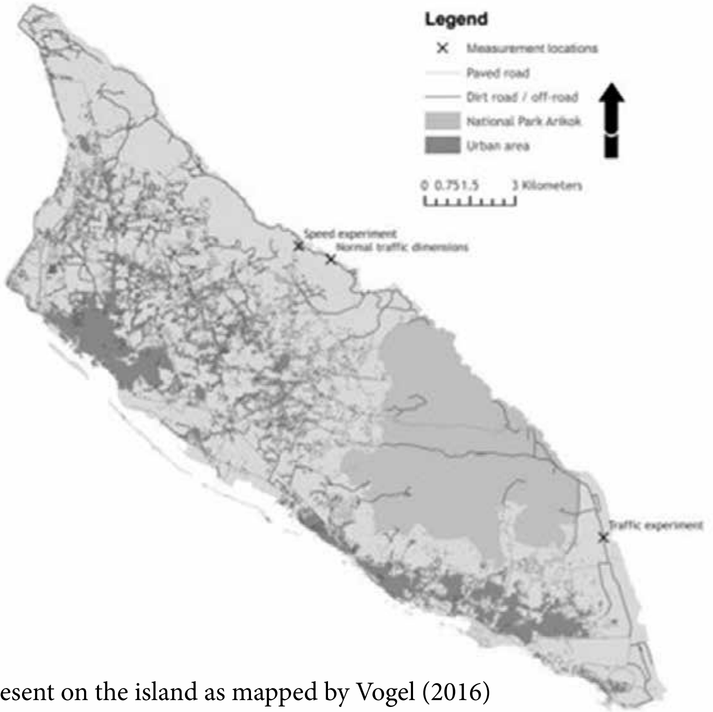
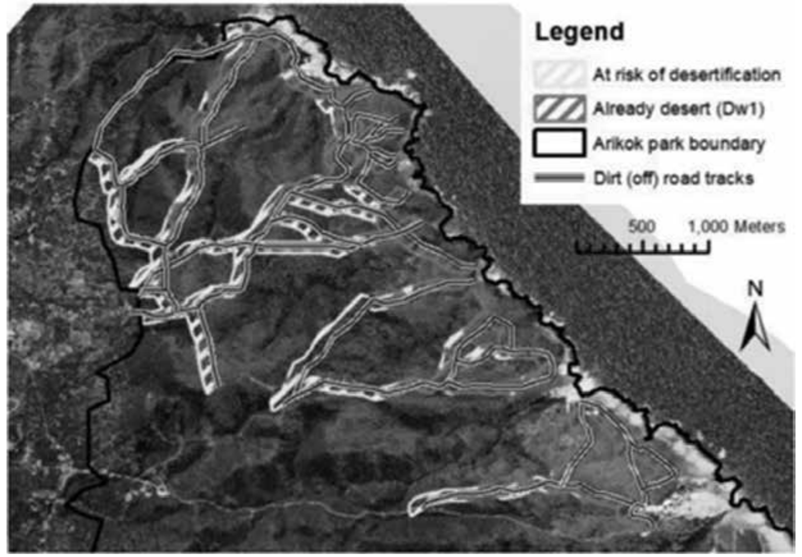


Figure 7: Dust roads present on the island as mapped by Vogel (2016)

The extent of the impacts of off-road driving on Aruba has partially been touched upon in earlier research projects on Aruba. A study was done on the dynamics of the dust emissions on Aruba, looking mostly at the dust transport dynamics in relation to Aruban soil types, vehicle speeds, and vehicle types (Vogel, 2017). This study found that the vehicles on Aruba were indeed producing dust pollution that exceeded natural background deposition rates, up to almost 60 g m-2 h-1 close to the road (Vogel, 2017).

Another study (Oosterhuis, 2016) was conducted to map the vegetation of Parke Arikok, in which the dust roads used at the time were marked out together with a theoretical risk map based on known effects of dust emissions, as can be seen in Figure 8. In this study, the impacts, specifically on the vegetation, were posed as a future research area.

Through personal communications with stakeholders the main dust road from the Shete National Park entrance to Conchi Natural Pool was explained to be one of the busiest and most trafficked roads, due to the attraction of swimming in the natural pool. In addition the management of Parke Arikok indicated an interest in knowing the impact of this road upon the vegetation. Due to this, and the necessity to select feasible scope for my research, this dust road was chosen as the main experimental study area.



A theoretical map of vegetation at risk of degradation due to the effects of off-road driving, taken from (Oosterhuis, 2016)

3.7 Shete - Conchi Dust Road

To gain a better understanding of the extent of off-road driving occurring within the study area, informal counts of vehicle traffic was made along the Shete to Conchi dust road during LFA fieldwork days (Feb-March, 2019). Informal observations were being made on the quantity, type and driving pattern (behavior/speed/keeping to the roads) of any vehicles driving on the Shete-Conchi road. From personal observation tours with specific companies driving on an decently scheduled basis (with fluctuations to allow for traffic), this notion was also confirmed in personal communication with Park Officials regarding tour vehicle presence in the park.

Only vehicles travelling towards Conchi were counted, to minimize potential miscounting and double counting of returning vehicles. Due to counting locations being on the Shete-Conchi dust road, and the Shete entrance only officially opened at 9:00am, vehicles seen prior to 9:00am were counted as "before hour" vehicles, as well as those entering the park after 15:30 when the Shete entrance closed. The values may also be undercounted due to main attention being focused on LFA data collection. Human error in counting may have occurred as such values were rounded to the nearest 5.

The average observed quantity of tour vehicles during opening hours was around 200-350 tour vehicles and 80 individual cars, on several (three) early morning 30-70 pre-opening hour tour vehicles were counted. During several (four) afternoons (15:30-17:00) 50-85 tour and 20+ individual vehicles were counted and during two (two) later evenings (17:00-19:30) an additional 60-90 tour and 20+ individual vehicles were counted.

If daily schedule continuity is assumed, - as well as the consistency of "random visitors"- a daily average for the Shete to Conchi road is 510-715 vehicles, making a round-trip, resulting in 1020-1430 one-way journeys and dust emissions. From personal observations almost all vehicles were travelling over the park's speed limit of 20km/h (unless waiting in a traffic jam due to large quantities of vehicles waiting to pass "one-lane" road segments). Furthermore, on several occasions individuals under the age of 18 were seen driving the vehicles, as well as multiple drivers whom were not confident in their off-road driving ability. Several observations were also made of vehicles driving outside of the dust-road boundaries.

4. Materials and Methods

4.1Research Questions and Sub-Questions

1. What are the impacts of off-road vehicle traffic on landscape functionality of the Aruban xeric shrubland ecosystem?
    a. What is the extent of off-road vehicle usage and traffic on Aruba?
    b. Is there a statistically significant difference in LFA values between areas exposed to off-road traffic and control areas?
    c. How big is the difference in landscape functionality between roadside and non-roadside locations?
    d. How do the soil quality, water infiltration, nutrient cycling LFA index values compare between research conditions?
    e. How does the vegetation cover compare between research conditions?
    f. Do the LFA index values differ within patch types between research conditions?

4.2 Hypothesis

Based on literature about the effects of off-road vehicle traffic and dust deposition on vegetation the difference in land functionality between dust-road roadsides and non-roadside locations is expected to be statistically significant. As such, my main research hypothesis is that there is a difference in land functionality between roadside and non-roadside conditions.

4.3Experimental Design

In order to assess the impact of off-road vehicle traffic on the landscape functionality of the Aruban xeric shrubland ecosystem, a pair-based experimental design was set up. A pair was made of two plots, one adjacent to the dust road (roadside) and one in a control zone (non-roadside). Land functionality indicators were measured in both to then run a paired t-test (see Methodology 4.6)

Due to desire to exclude the influence of other variables as impacting land functionality, a series of control conditions were set-up, and pair-based locations were selected so as to be homogenous within these. These control variables are elements that, according to literature, may influence vegetation growth, nutrient cycling, water infiltration and soil quality in arid ecosystems.

As such, the experimental conditions are 1) the roadside condition (R) – plots adjacent or starting within 10m downwind of the Shete – Conchi dust roads, and 2) the non-roadside condition (N) – plots not within 200m downwind of an active dust road.

The 200m distance was chosen due to literature (Vogel, 2017) suggesting that Aruban dust deposition stayed constant after this distance, and longer distances would greatly diminish the locations available for paired plot locations due to the extensive control variables.

4.3.1 Control Variables

The control variables were:

- Distance from ocean (for salinity and direct wind purposes) (Denters, 1979)
  - o Within the same range (100–499m, 500-999m, 1000-1499m, 1500+)
- Slope direction (for wind purposes) (Denters, 1979; Tongway & Hindley, 2004b)
  - o Within 45° on transect compass bearings
- Slope angle & transect location on slope (for run-off strength purposes) (Tongway & Hindley, 2004a)
  - o Within same category (slight, moderate, steep)
  - o Within same category (upper, mid, lower)
- Elevation (Denters, 1979)
  - o Within 50m from each other
- Lithography (hydrology) (Denters, 1979; Oosterhuis, 2016; Stoffers, 1956)
  - o Within same category (Aruba Lava Formation, Limestone, Tonalite)

4.3.2 Sample Size

Statistical tests require minimum sample sizes to have enough power to be statistically viable. In order to determine the required sample size (number of pairs) for location selection, a power test was run using the expected mean and standard deviation of the LFA value difference scores. The expected mean difference was 10, with a standard deviation of five, meaning a minimum of five pairs (10 locations) was required for statistical validity.

A total of 14 locations (seven pairs) were completed and analysed for this collected paper, and additional locations will be done for the final thesis.

4.4 Data Analysis

Paired t-tests will be run to analyse difference scores for the location LFA index values, vegetation cover percentages, patch type LFA index values between the experimental conditions.

As my main research hypothesis is that there is a difference in land functionality between roadside and non-roadside conditions, the null hypothesis (H0) -namely, there is no difference in land functionality between roadside and non-roadside conditions- was established for statistical testing.

4.5 Site Descriptions

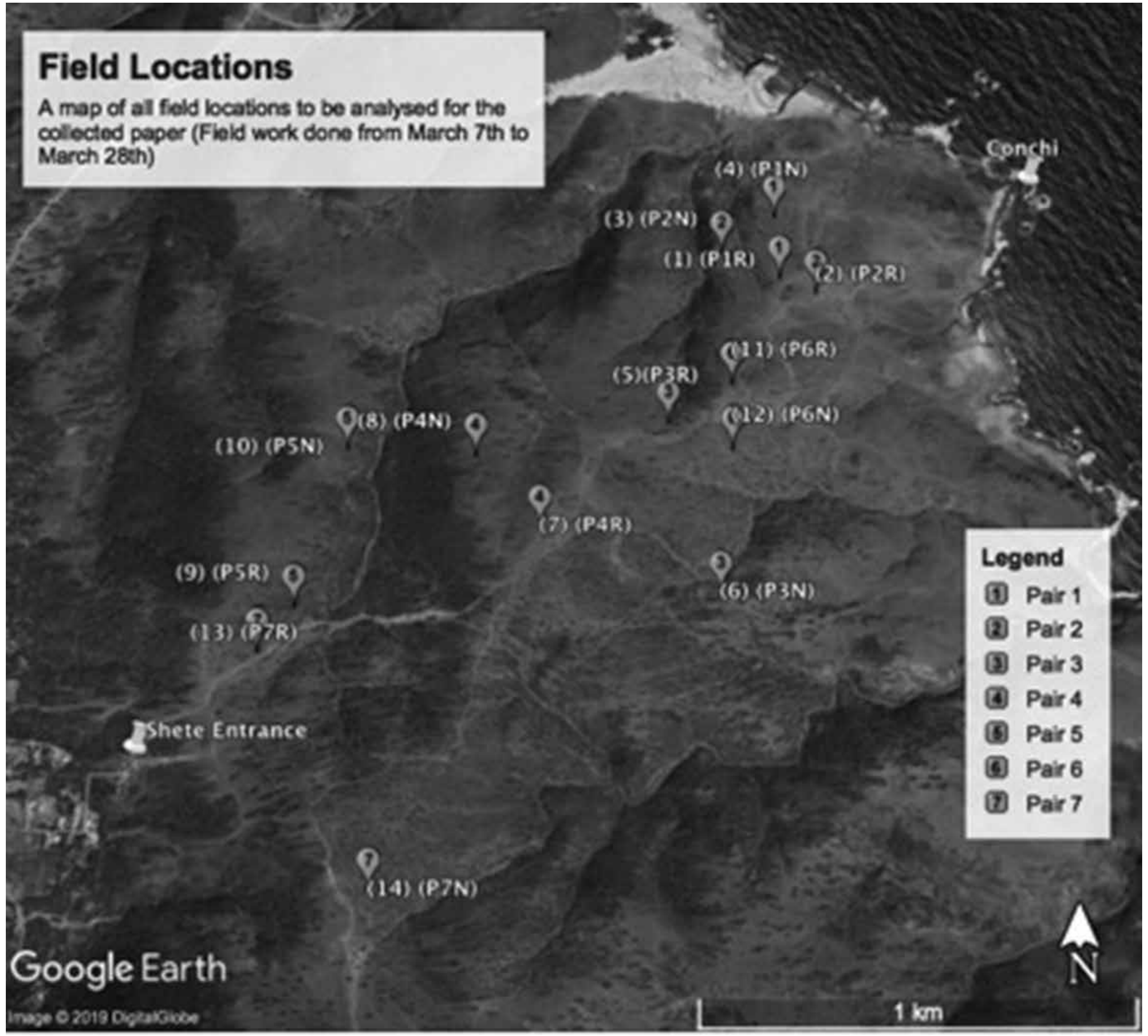


Figure 9: Map of Field Locations

Pair 1 – *Location 1 (P1R) & 4 (P1N)*
GPS Co-ordinates: 12° 31' 20" N 69°56'02" W & 12°31'25" N 69°56'01 W
Distance from Ocean: 430m & 280 m
Transect Compass Bearings (Slope Direction): 288°W & 315°NW
Slope Angle: Slight & Slight
Elevation: 60m & 40m
Slope Topographical Location: Upper & Upper/Mid Slope
Lithography: Aruba Lava Formation & Aruba Lava Formation
General Comments: The roadside plot was adjacent to one of the highest trafficked dust roads in the Shete-Conchi "Delta". This close to the coast, vegetation was patchy everywhere, with quite direct wind exposure. The non-roadside plot was within 200m of a dust road that had one vehicle on it during the entire field day, but otherwise, was within similar conditions. Due to difficulties finding an alternative pair location, and the general "abandoned" dust road was deemed insignificant enough to be negligible, this pair was deemed acceptable.

Pair 2 – *Location 2 (P2R) & 3 (P2N)*
GPS Co-ordinates: 12° 31' 21" N 69° 55' 59" W & 12°31'25"N 69°56'06" W
Distance from Ocean: 350m & 380m
Transect Compass Bearings (Slope Direction): 131° SE & 113° SEE
Slope Angle: Medium & Medium
Elevation: 60m & 50m
Slope Topographical Location: Upper & Upper
Lithography: Aruba Lava Formation & Aruba Lava Formation
General Comments: This roadside plot is a "rectangle" of land in between a several dust roads in the dust road "Delta" just prior to Conchi and is not sheltered from the direct wind, and the non-roadside plot is not sheltered from the wind, the lower slope is adjacent to the rooi and quite steep but the upper hill has medium slope angles, location chosen was outside of rooi influence area. As such, all the characteristics matched up, and the pair was deemed acceptable.

Pair 3 – *Location 5 (P3R) & 6 (P3N)*
GPS Co-ordinates: 12°31'10" N 69 °56'11" W & 12°30'57" N 69 °56'7" W
Distance from Ocean: 770m & 800m
Transect Compass Bearings (Slope Direction): 30° NE & 5°N
Slope Angle: Slight & Slight
Elevation: 100m & 90m
Slope Topographical Location: Upper & Upper
Lithography: Aruba Lava Formation & Aruba Lava Formation
General Comments: This conditions are very similar, the data were collected on different days due to rainfall after completion of location five, but the pair was deemed acceptable.

Pair 4 – *Location 7 (P4R) & 8 (P4N)*
GPS Co-ordinates: 12°31'2" N 69 °56'21" W & 12°31'4" N 69 °56'26" W
Distance from Ocean: 1100m & 1200m
Transect Compass Bearings (Slope Direction): 122°SE & 103°E
Slope Angle: Very Slight & Very Slight
Elevation: 130m & 140m
Slope Topographical Location: Upper & Upper
Lithography: Aruba Lava Formation & Aruba Lava Formation
General Comments: The non-road plot is within eyesight of a busy road, but outside of the established 200m downwind from a busy road. As such, pair was deemed acceptable.

Pair 5 – *Location 9 (P5R) & 10 (P5N)*
GPS Co-ordinates: 12°30'56" N 69 °56'40" W & 12°31'8" N 69 °56'36" W
Distance from Ocean: 1850m & 1500m
Transect Compass Bearings (Slope Direction): 96°E & 114°E
Slope Angle: Medium & Medium
Elevation: & 110m
Slope Topographical Location: Mid/Lower & Mid/Upper
Lithography: Aruba Lava Formation & Aruba Lava Formation
General Comments: Both these locations are part of the same south-facing rooi hill slope (Rooi Fluit) but both locations were selected mid slope so as to be outside of the direct rooi influence. Both sites have equal wind protection from higher hill slopes breaking direct wind, and as such, the difference in distance from ocean is negligible. This pair was deemed acceptable.

Pair 6– *Location 11 (P6R) & 12 (P6N)*
GPS Co-ordinates: 12°31'13" N 69 °56'6" W & 12°31'8" N 69 °56'9" W
Distance from Ocean: 580m & 630m
Transect Compass Bearings (Slope Direction): 44°N & 65°NE
Slope Angle: Medium & Medium
Elevation: 110m & 100m
Slope Topographical Location: Upper & Upper
Lithography: Aruba Lava Formation & Aruba Lava Formation
General Comments: These locations were spatially close to each other, but on parallel hill slopes of different ridges. The non-roadside plot was within eyesight of several dust roads, but not within 200m downwind of any of them. As such, this pair was deemed acceptable.

Pair 7– *Location 13 (P7R) & 14 (P7N)*
GPS Co-ordinates: 12°30'56" N 69 °56'31" W & 12°30'35"N 69° 56' 34"W
Distance from Ocean: 1800m & 1850m
Transect Compass Bearings (Slope Direction): 140°SE 164°S
Slope Angle: Medium & Medium
Elevation: 130m & 160
Slope Topographical Location: Midslope & Midslope
Lithography: Aruba Lava Formation & Aruba Lava Formation
General Comments: The locations are both very inland, close to western park borders. The roadside location is on the first hill slope just after the Shete entrance, in between a dust road going up the hill and the main dust road to Conchi heading east. The non-roadside location is within 200m upwind from the dust road from Sero Arikok to Conchi, but as such, deemed outside the downwind dust pollution zone. The pair was deemed acceptable.

4.6 Methodology

The Landscape Function Analysis (LFA) is a method that uses rapid and simple field-observed surface indicators to assess the functioning of an ecosystem at a hill slope scale (Tongway & Hindley, 2004c). This method allows for 1) the analysis of vegetation cover and types – through spatial analysis of different vegetation patch types and bare-ground inter-patches (the Landscape Organisation Assessment (LOA) component), as well as 2) the assessment of their functional status through the use of soil surface indicators relating to the functioning of water infiltration, nutrient cycling and soil quality (the Soil Surface Assessment (SSA) component).

From there, indices on the soil quality, water infiltration and nutrient cycling are calculated.

The LFA consists of these three major components as well as the calculations (data reduction and tabulation). These major components are 1) describing the geographic setting of the site, 2) characterizing landscape organisation and spatial distribution of fertile patches and inter-patches and 3) the soil surface assessment (SSA) of each patch / inter-patch types identified in step two.

4.6.1. Step 1: Describing Geographic Setting of the Plot

In this step, the objective is to identify the location of a plot within its landscape and to gather data on its values for the control variables to ensure field suitability for planned location pairing. The details collected include GPS location, elevation, transects' compass bearing (slope direction), slope (slope angle), lithology, distance from ocean, and soils.

In addition, the topographic location of the site within the overall landform pattern is recorded to further correct for this in locations pairings. The topographic identifications shown in Figure 10 are possible, but in this study location choices were limited to crests and upper, mid, and lower slope locations.

4.6.2 Step 2: Landscape Organisational Analysis (LOA)

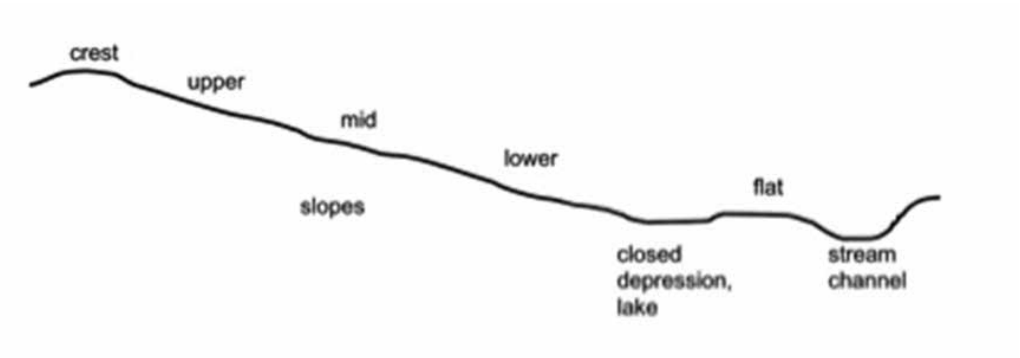


Figure 10: The identification of topographic position in the landscape adapted from Tongway & Hindley, 2004.

In this step, the spatial organisation and vegetation cover proportions are estimated using a combination of at three or four 4 20-30m transects (combining to a minimum of 100m) along which patches were identified and their spatial metrics (length and cross-section width) were measured. Transects were started upslope, and aligned with main slope and run-off directions. The first transect was set at the corner of the patch area, and consequent transects were set 15m apart in a semi-parallel orientation depending on slope direction variations. This was done to minimize transect selection for interesting patches. Both GPS location and transects' compass bearing were recorded.

Along a transect, the patches and inter-patches were identified, their spatial metrics recorded, and observations about other lithographic elements such as rills, canopy covers and major landmarks were noted. The patch identification categories established for this fieldwork were as follows: Tree (T), Acacia (A), Tall Cacti (Ct), Small Cacti (Cs), Shrub (S), Grass (G), Shrub Log Complex (L) and Bare ground (B) (see Table 1 for further details). Patches are separated by bare-ground, any singular patch with mixed category presence will be noted as such in the data sheets but will be treated as belonging to the patch type with majority cover presence (if <60%). Spatial metrics were recorded for the ground cover of a patch, this involved measuring the patch length along the transect line and the run-off obstruction width of a path as shown in Figure 11 – ground cover in this case was to mean the basal cover and any adjacent area covered by litter as explained in Table 1. This means that area covered by the canopy of the vegetation was not considered part of the patch unless there was evidence of shielding and build-up to indicate ground-level obstruction of run-off flow. Figure 12 shows additional examples of patch length and obstruction width measurement. Canopy measurements were recorded on the LOA as a "sub-category" of bare ground patch, alongside different extents of ground cover via other non-vegetation means and other factors, so as to enable selection of "representative" canopy covered bare-ground patches in the SSA selections.

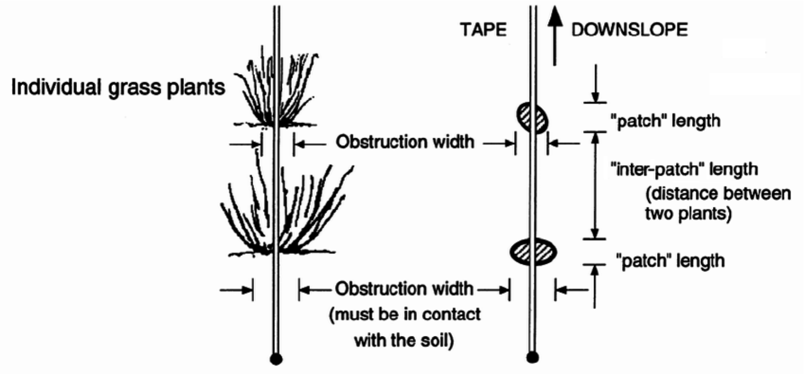


Figure 11: Diagrammatic illustration of obstruction width and patch length of a grass patch.

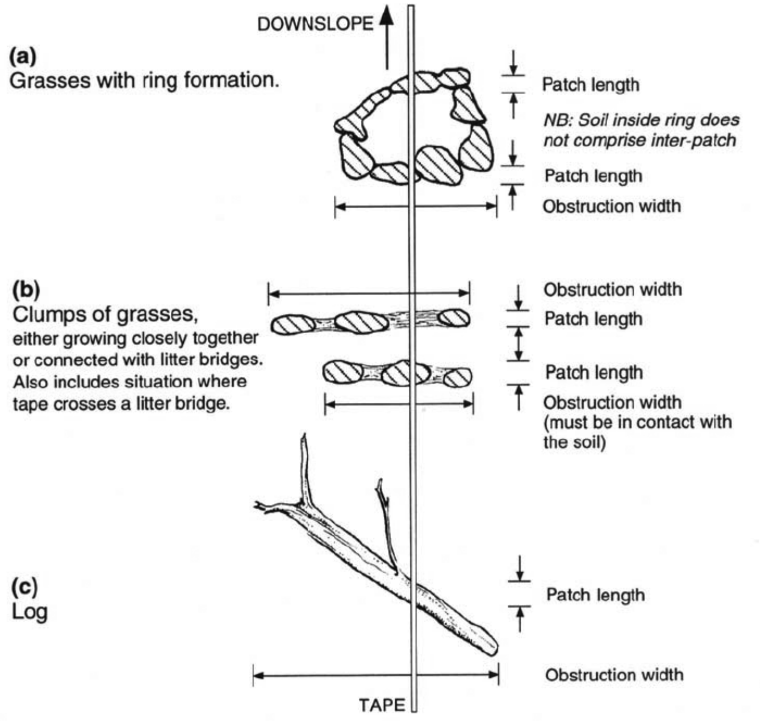


Figure 12: A diagrammatic illustration of how to measure obstruction width and patch lengths of complicated patches.

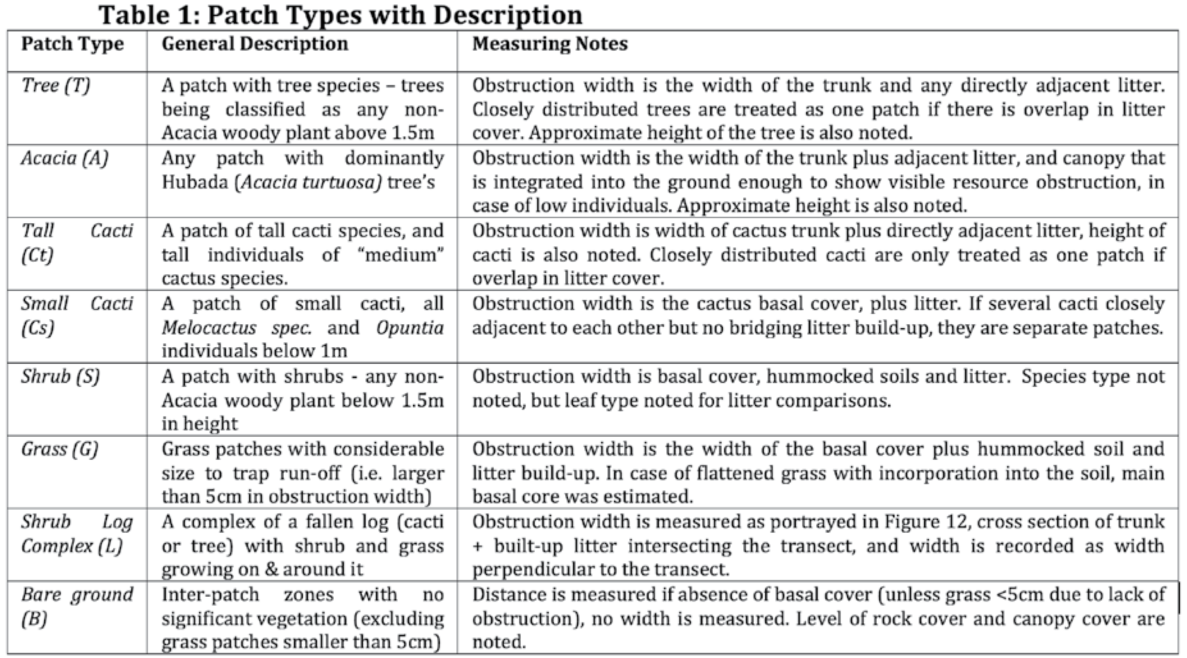


Table 1: Patch Types with Description

Patch Type	General Description	Measuring Notes
Tree (T)	A patch with tree species – trees being classified as any non-Acacia woody plant above 1.5m	Obstruction width is the width of the trunk and any directly adjacent litter. Closely distributed trees are treated as one patch if there is overlap in litter cover. Approximate height of the tree is also noted.
Acacia (A)	Any patch with dominantly Hubada (*Acacia turtuosa)* tree's	Obstruction width is the width of the trunk plus adjacent litter, and canopy that is integrated into the ground enough to show visible resource obstruction, in case of low individuals. Approximate height is also noted.
Tall Cacti (Ct)	A patch of tall cacti species, and tall individuals of "medium" cactus species.	Obstruction width is width of cactus trunk plus directly adjacent litter, height of cacti is also noted. Closely distributed cacti are only treated as one patch if overlap in litter cover.
Small Cacti (Cs)	A patch of small cacti, all *Melocactus spec.* and *Opuntia* individuals below 1m	Obstruction width is the cactus basal cover, plus litter. If several cacti closely adjacent to each other but no bridging litter build-up, they are separate patches.
Shrub (S)	A patch with shrubs - any non-Acacia woody plant below 1.5m in height	Obstruction width is basal cover, hummocked soils and litter. Species type not noted, but leaf type noted for litter comparisons.
Grass (G)	Grass patches with considerable size to trap run-off (i.e. larger than 5cm in obstruction width)	Obstruction width is the width of the basal cover plus hummocked soil and litter build-up. In case of flattened grass with incorporation into the soil, main basal core was estimated.
Shrub Log Complex (L)	A complex of a fallen log (cacti or tree) with shrub and grass growing on & around it	Obstruction width is measured as portrayed in Figure 12, cross section of trunk + built-up litter intersecting the transect, and width is recorded as width perpendicular to the transect.
Bare ground (B)	Inter-patch zones with no significant vegetation (excluding grass patches smaller than 5cm)	Distance is measured if absence of basal cover (unless grass <5cm due to lack of obstruction), no width is measured. Level of rock cover and canopy cover are noted.

Table 1: Patch Types with Description

4.6.3 Step 3: Soil Surface Assessment

Once an organisational analysis of the landscape of a plot has been completed, soil surface assessments (SSA) were performed on each patch and inter-patch type. Per patch and inter-patch type it was aimed to do five SSA sub-plots, but in practice for most patch types there were less than five plots present for an SSA, so as many as were possible were done. The sub-plots aimed to be 1mx1m, but due to patch sizes in practice a varied sub-plot size proportional to the patch size selected for SSA was used.

If more than five patches were available of a specific patch type, then five random and representative patches were selected, through looking at proportion of patches with other identifiable features and selecting patches with a representative proportion of these identifiable features.

The soil surface assessment was done according to the LFA Methodology (Tongway & Hindley, 2004a) and involves simple visual indicators, rainsplash protection, perennial vegetation cover, litter (cover, origin, decomposition/ incorporation), cryptogram cover, crust brokenness, soil erosion type and severity, deposited materials, soil surface roughness, surface nature, slake test, and soil texture. (See Tongway & Hindley, 2004 for full protocol).

4.6.4 Step 4: Landscape Functional Analysis/Indicator Calculation

Once the data is completed and the data has been gathered, it will be entered into the LFA spread sheets that come with the LFA field manual (Tongway & Hindley, 2004a). This will then be used to estimate the stability, water infiltration and nutrient cycling indices based on different combinations and weightings of the indicators. The relation of the different indicators to the landscape functionality indices is shown in Table 2.

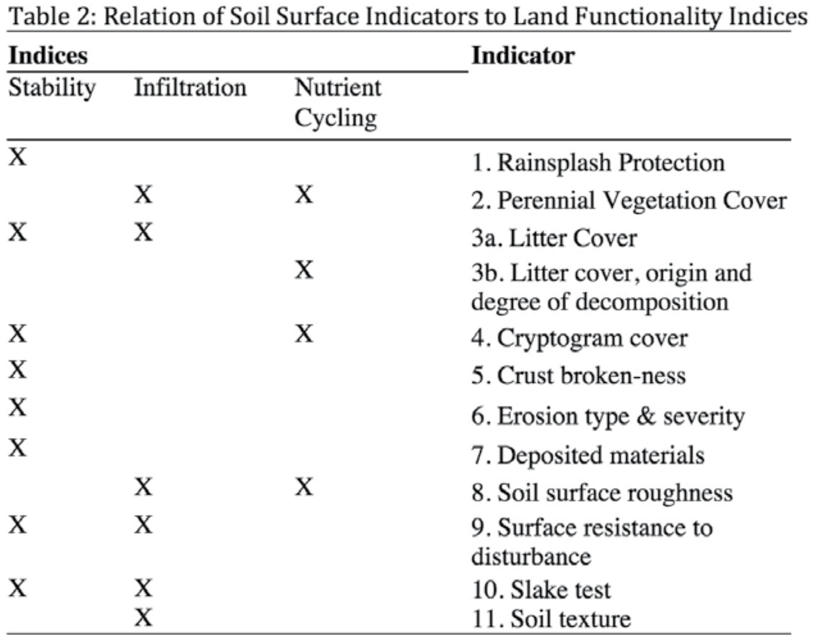


Table 2: Relation of Soil Surface Indicators to Land Functionality Indices

Indices			**Indicator**
Stability	Infiltration	Nutrient Cycling	
X			1. Rainsplash Protection
	X	X	2. Perennial Vegetation Cover
X	X		3a. Litter Cover
		X	3b. Litter cover, origin and degree of decomposition
X		X	4. Cryptogram cover
X			5. Crust broken-ness
X			6. Erosion type & severity
X			7. Deposited materials
	X	X	8. Soil surface roughness
X	X		9. Surface resistance to disturbance
X	X		10. Slake test
	X		11. Soil texture

Table 2: Relation of Soil Surface Indicators to Land Functionality Indices

5. Data

5.1Landscape Functionality in Both Experimental Conditions

Figure 13 shows the spread of the LFA values per calculated index, with the orange boxes being those for the roadside plots and the yellow those for the non-roadside plots. The specific calculated data points and the results of the paired t-tests are shown in Table 3, Table 4, and Table 5.

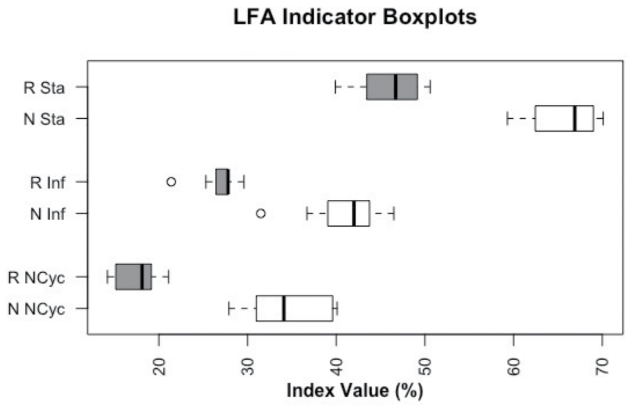


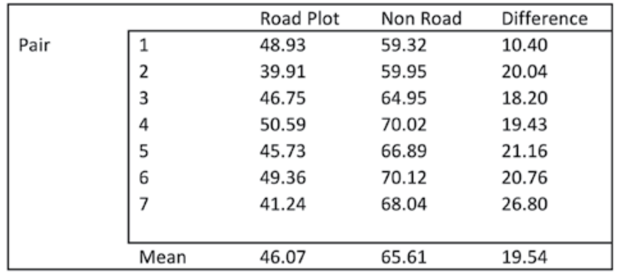
Figure 13: Boxplot of LFA Values for Pair 1-7.

5.1.1Stability Index

The stability index is calculated by combining surface indicators: rainsplash protection, litter cover, cryptogram cover, crust brokenness, erosion type and severity, deposited materials, surface resistance, and the slake test.

There was a statistically significant difference in the scores for roadside (M=46.06, SD=4.12) and non-roadside (M=65.60, SD=4.44) conditions; t (6)=10.61, p=<0.001.

Table 3: Stability Index



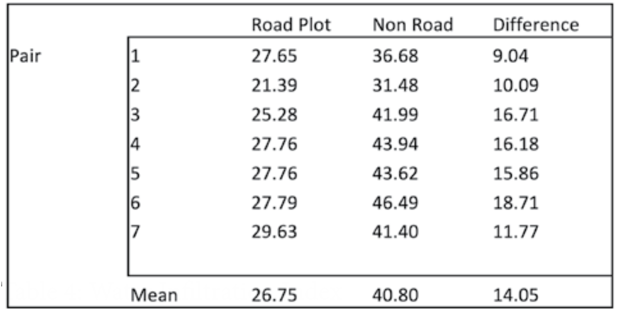
		Road Plot	Non Road	Difference
Pair	1	48.93	59.32	10.40
	2	39.91	59.95	20.04
	3	46.75	64.95	18.20
	4	50.59	70.02	19.43
	5	45.73	66.89	21.16
	6	49.36	70.12	20.76
	7	41.24	68.04	26.80
	Mean	46.07	65.61	19.54

5.1.2Water Infiltration Index

The water infiltration index is calculated by combining surface indicators: perennial vegetation cover, litter cover, soil surface roughness, surface resistance to disturbance, slake test and soil texture.

There was a statistically significant difference in the scores for roadside (M=26.75, SD=2.67) and non-roadside (M=40.80, SD=5.08) conditions; t (6)=10.11, p=<0.001.

Table 4: Water Infiltration Index



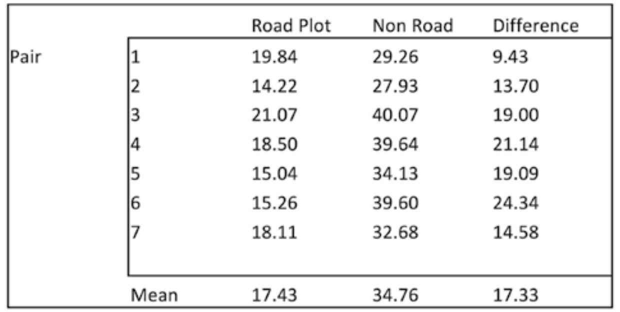
		Road Plot	Non Road	Difference
Pair	1	27.65	36.68	9.04
	2	21.39	31.48	10.09
	3	25.28	41.99	16.71
	4	27.76	43.94	16.18
	5	27.76	43.62	15.86
	6	27.79	46.49	18.71
	7	29.63	41.40	11.77
	Mean	26.75	40.80	14.05

5.1.3 Nutrient Cycling Index

The nutrient cycling index is calculated by combining surface indicators: perennial vegetation cover, litter cover (including origin and degree of decomposition), cryptogram cover, and soil surface roughness.

There was a statistically significant difference in the scores for roadside (M=17.43, SD=2.63) and non-roadside (M=34.76, SD=5.11) conditions; t (6)=9.15, p=<0.001.

Table 5: Nutrient Cycling Index



		Road Plot	Non Road	Difference
Pair	1	19.84	29.26	9.43
	2	14.22	27.93	13.70
	3	21.07	40.07	19.00
	4	18.50	39.64	21.14
	5	15.04	34.13	19.09
	6	15.26	39.60	24.34
	7	18.11	32.68	14.58
	Mean	17.43	34.76	17.33

5.2 Further Data Analysis

Further data analysis will still be conducted on the vegetation cover percentages and how those differ between the experimental conditions. Data analysis will also still be carried out for the LFA index values of the different patch types and how those may differ between the experimental conditions. Additionally, a breakdown will be done of the surface indicators and their relative contribution to the index values, to note which components are the biggest contributors to the differences in landscape functionality.

Trends in the spatial metrics of patches and inter-patches, of specific patch types and between experimental conditions will also be analysed.

In addition, satellite imagery analysis of the dust roads in Parke Arikok will be finalised to visualise the scope of potential impact by dust roads on the vegetation.

6 Bibliography

- Aguiar, M. R., Paruelo, J. M., Sala, O. E., & Lauenroth, W. K. (1996). Ecosystem responses to changes in plant functional type composition: An example from the Patagonian steppe. Journal of Vegetation Science, 7(3), 381–390. https://doi.org/10.2307/3236281
- Aguiar, M. R., & Sala, O. E. (1999). Patch structure, dynamics and implications for the functioning of arid ecosystems. Trends in Ecology & Evolution, 14(7), 273–277. https://doi.org/10.1016/S0169-5347(99)01612-2
- Alofs, L. (1997, May). Brasilkap in de jaren rond 1840. StimAruba Tijdschrift: Revista Di Organisacion Pa Naturalesa STIMARUBA. Tema Di e Edicion Aki: Flora Di Aruba, 8.
- Amiri, F., Ariapour, A., & Fadai, S. (2008). Effects of Livestock Grazing on Vegetation Composition and Soil Moisture Properties in Grazed and Non-Grazed Range Site. Journal of Biological Sciences, 8(8), 1289–1297. https://doi.org/10.3923/jbs.2008.1289.1297
- Asner, G. P., Elmore, A. J., Olander, L. P., Martin, R. E., & Harris, A. T. (2004). GRAZING SYSTEMS, ECOSYSTEM RESPONSES, AND GLOBAL CHANGE. Annual Review of Environment and Resources, 29(1), 261–299. https://doi.org/10.1146/annurev.energy.29.062403.102142
- Bates, G. H. (1935). The Vegetation of Footpaths, Sidewalks, Cart-Tracks and Gateways. The Journal of Ecology, 23(2), 470. https://doi.org/10.2307/2256132
- Bilotta, G. S., Brazier, R. E., & Haygarth, P. M. (2007). The Impacts of Grazing Animals on the Quality of Soils, Vegetation, and Surface Waters in Intensively Managed Grasslands (pp. 237–280). https://doi.org/10.1016/S0065-2113(06)94006-1
- Brown, C. J., Saunders, M. I., Possingham, H. P., & Richardson, A. J. (2013). Managing for Interactions between Local and Global Stressors of Ecosystems. PLoS ONE, 8(6), e65765. https://doi.org/10.1371/journal.pone.0065765
- Brown, J. H., Valone, T. J., & Curtin, C. G. (1997). Reorganization of an arid ecosystem in response to recent climate change. Proceedings of the National Academy of Sciences of the United States of America, 94(18), 9729–9733. https://doi.org/10.1073/PNAS.94.18.9729
- Buckley, R. (2004). Environmental impacts of motorized off-highway vehicles. In Environmental impacts of ecotourism (pp. 83–97). Wallingford: CABI. https://doi.org/10.1079/9780851998107.0083
- Campbell, K., & Donlan, C. J. (2005). Feral Goat Eradications on Islands. Conservation Biology, 19(5), 1362–1374. https://doi.org/10.1111/j.1523-1739.2005.00228.x
- CBS. (n.d.). General Visitor Statistics. Retrieved April 3, 2019, from http://cbs.aw/wp/index.php/category/tourism/general-visitors-statistics/
- Conservation, A. B. (n.d.). Aruba Birdlife Conservation.
- Coughenour, M. B. (1991). Invited Synthesis Paper: Spatial Components of Plant-Herbivore Interactions in Pastoral, Ranching, and Native Ungulate Ecosystems. Journal of Range Management, 44(6), 530. https://doi.org/10.2307/4003033
- County, K., & Report, C. (2008). 2007 Climate Report. Transportation. Seru Mahuma. Retrieved from http://www.meteo.an
- D'Odorico, P., Bhattachan, A., Davis, K. F., Ravi, S., & Runyan, C. W. (2013). Global desertification: Drivers and feedbacks. Advances in Water Resources, 51, 326–344. https://doi.org/10.1016/J.ADVWATRES.2012.01.013
- Darley, E. F. (1966). Studies on the effect of cement-kiln dust on vegetation. Journal of the Air Pollution Control Association, 16(3), 145–150. https://doi.org/10.1080/00022470.1966.10468456
- Denters, P. (n.d.). Aruba: Nationaal Park Jamanota. Ontwikkelingsplan voor het nationaal park Jamanota.
- Denters, P. (1979). Aspecten van de vegetatie op Aruba, Nederlandse Antillen, waaronder de relatie tussen de windsterkte en de opbouw en samenstelling van de

vegetatie.

- Departamento Meteorologico Aruba. (2010). Summary Climatological Normals, Period 1981-2010. Retrieved from http://www.meteo.aw/files/Download/climatnormals19812010.pdf
- Departamento Meteorologico Aruba. (2019). ARUBA CLIMATOLOGICAL SUMMARY 2018. Oranjestad. Retrieved from http://www.meteo.aw/files/Download/aruba_rep_2018.pdf
- Ecology Pocket Guide. (n.d.-a). Desert and Xeric Shrubland — Ecology Pocket Guide. Retrieved April 5, 2019, from http://www.ecologypocketguide.com/desertsandxericshrubland/
- Ecology Pocket Guide. (n.d.-b). Ecology Types — Ecology Pocket Guide. Retrieved April 5, 2019, from http://www.ecologypocketguide.com/ecologytypes#/tropical-and-subtropical-dry-broadleaf-forest/
- Emberson, L. D., Ashmore, M. R., Murray, F., Kuylenstierna, J. C. I., Percy, K. E., Izuta, T., … Domingos, M. (2001). Impacts of air pollutants on vegetation in developing countries. Water, Air, and Soil Pollution, 130(1–4), 107–118. https://doi.org/10.1023/A:1012251503358
- Etyemezian, V., Ahonen, S., Nikolic, D., Gillies, J., Kuhns, H., Gillette, D., & Veranth, J. (2004). Deposition and removal of fugitive dust in the arid southwestern united states: Measurements and model results. Journal of the Air and Waste Management Association, 54(9), 1099–1111. https://doi.org/10.1080/10473289.2004.10470977
- Fajardo, L., González, V., Nassar, J. M., Lacabana, P., Portillo, C. A., Biotropica, S., … Rodriguez, J. P. (2012). Tropical Dry Forests of Venezuela : Characterization and Current Conservation Status Tropical Dry Forests of Venezuela : Characterization and Current Conservation Status ' (Vol. 37). Retrieved from https://www.jstor.org/stable/pdf/30043221.pdf?refreqid=excelsior%3A012906962c5ab7d3b477233bc3686602
- Farmer, A. M. (1993). The effects of dust on vegetation-a review. Environmental Pollution, 79(1), 63–75. https://doi.org/10.1016/0269-7491(93)90179-R
- Forman, R. T. T., & Alexander, L. E. (1998). Roads and their Major Ecological Effects. Annu. Rev. Ecol. Syst (Vol. 29). Retrieved from www.annualreviews.org
- Glendening, G. E. (1952). Some Quantitative Data on the Increase of Mesquite and Cactus on a Desert Grassland Range in Southern Arizona. Ecology, 33(3), 319–328. https://doi.org/10.2307/1932827
- Goossens, D. (2005). Quantification of the dry aeolian deposition of dust on horizontal surfaces: An experimental comparison of theory and measurements. Sedimentology, 52(4), 859–873. https://doi.org/10.1111/j.1365-3091.2005.00719.x
- Goossens, D., & Buck, B. (2009). Dust emission by off-road driving: Experiments on 17 arid soil types, Nevada, USA. Geomorphology, 107(3–4), 118–138. https://doi.org/10.1016/J.GEOMORPH.2008.12.001
- Goossens, D., & Buck, B. (2014). Dynamics of Dust Clouds Produced by Off-road Vehicle Driving. Journal of Earth Sciences and Geotechnical Engineering (Vol. 4). Scienpress Ltd. Retrieved from https://s3.amazonaws.com/academia.edu.documents/35603709/Goossens_and_Buck_2014.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1554486142&Signature=6%2B5kNfcthdH0OkhEMv%2FN3KYWQak%3D&response-content-disposition=inline%3Bfilename%3DDynamics_of_dust_clou
- Hiernaux, P., Bielders, C. L., Valentin, C., Bationo, A., & Fernández-Rivera, S. (1999). Effects of livestock grazing on physical and chemical properties of sandy soils in Sahelian rangelands. Journal of Arid Environments, 41(3), 231–245. https://doi.org/10.1006/JARE.1998.0475
- Industries, M. of. (n.d.). Aruba [History of Industries]. Santa Cruz, Aruba.
- Jones, C., Newsome, D., & Macbeth, J. (2016). Governance and environmental implications of motorised events: insights from Australia and avenues for further inquiry. Current Issues in Tourism, 19(7), 680–696. https://doi.org/10.1080/13683500.2013.854753
- Kuhns, H., Gillies, J., Etyemezian, V., Nikolich, G., King, J., Zhu, D., … Kohl, S. (2010). Effect of soil type and momentum on unpaved road particulate matter emissions from wheeled and tracked vehicles. Aerosol Science and Technology, 44(3), 187–196. https://doi.org/10.1080/02786820903516844
- Kutiel, P., Eden, E., & Zheveles, Y. (2002). Effect of experimental trampling and off-road motorcycle traffic on soil and vegetation of stabilized coastal dunes, Israel. Environmental Conservation, 27(1), 14–23. Retrieved from https://www.cambridge.org/core/journals/environmental-conservation/article/effect-of-experimental-trampling-and-offroad-motorcycle-traffic-on-soil-and-vegetation-of-stabilized-coastal-dunes-israel/34B35B0FB31B4329EA8D9744286784A2
- Kutiel, P., Zhevelev, H., & Harrison, R. (1999). The effect of recreational impacts on soil and vegetation of stabilised Coastal Dunes in the Sharon Park, Israel. Ocean and Coastal Management, 42(12), 1041–1060. https://doi.org/10.1016/S0964-5691(99)00060-5
- Köppen, W. (1900). Versuch einer Klassifikation der Klimate, vorzugsweise nach ihren Beziehungen zur Pflanzenwelt (Examination of a climate classification preferably according to its relation to the flora). Geogr. Zeitschr. Franz Steiner Verlag. https://doi.org/10.2307/27803924
- Lovich, J. E. (2002). Anthropogenic Degradation of the Southern California Desert Ecosystem and Prospects for Natural Recovery and Restoration. Environmental Management, 24(3), 309–326. https://doi.org/10.1007/s002679900235
- Mabbutt, J., & Floret, C. (1980). Case studies on desertification. Paris: United Nations Educational, Scientific and Cultural Organization. Retrieved from http://agris.fao.org/agris-search/search.do?recordID=FR9006410
- Matsuki, M., Gardener, M. R., Smith, A., Howard, R. K., & Gove, A. (2016). Impacts of dust on plant health, survivorship and plant communities in semi-arid environments. Austral Ecology, 41(4), 423–433. https://doi.org/10.1111/aec.12328
- Mwendera, E. J., & Saleem, M. A. M. (1997). Infiltration rates, surface runoff, and soil loss as influenced by grazing pressure in the Ethiopian highlands. Soil Use and Management, 13(1), 29–35. https://doi.org/10.1111/j.1475-2743.1997.tb00553.x
- N.V., G., & Sogreah. (1968). Water and land resources development plan for the islands of Aruba, Bonaire and Curaçao. Volume B: Inventory of land and water resources.
- Nolet, C., & M., V. (2009). Stofonderzoek Bonaire. Wageningen. Retrieved from http://www.dcbd.nl/sites/www.dcbd.nl/files/documents/Nolet%2C C.%2C Veen%2C M. van der%2C 2009. Stofonderzoek Bonaire%2C St Kibrahacha WUR.pdf
- Noy-Meir, I. (1973). Desert Ecosystems: Environment and Producers. Annual Review of Ecology and Systematics, 4(1), 25–51. https://doi.org/10.1146/annurev.es.04.110173.000325
- Noy-Meir, I. (1981). Spatial effects in modelling arid ecosystems. In D. W. Goodall & R. A. Perry (Eds.), Arid-land Ecosystems: Structure, Functioning and Management. London: Cambridge University Press. Retrieved from https://scholar.google.nl/scholar?hl=nl&as_sdt=0%252C5&q=36+Noy-Meir%252C+I.+%25281981%2529+Spatial+effects+in+modelling+of+arid+ecosystems%252C+in+Arid-land+Ecosystems%253A+Structure%252C+Functioning%252C+and+Management+%2528Vol.+2%2529+%2528Goodall%252C
- Oosterhuis, H. J. (2016). Landscape-ecological survey of Arikok National Park, Aruba: Restoring vegetation of a dry tropical island. Wageningen. Retrieved from http://www.dcbd.nl/sites/www.dcbd.nl/files/documents/Landscape-vegetation survey Arikok NP

Oosterhuis Henk Jan.pdf

- Peel, M. C., Finlayson, B. L., & McMahon, T. A. (2007). Updated world map of the Köppen-Geiger climate classification. Hydrology and Earth System Sciences, 11(5), 1633–1644. https://doi.org/10.5194/hess-11-1633-2007
- Polaszek, T., Lacle, F., van Beukering, P., & Wolfs, E. (2018). The Economics of Ecosystems and Biodiversity, Aruba. Retrieved from https://www.wolfscompany.com/wp-content/uploads/2018/04/TEEB-Aruba-Main-Report.pdf
- Rudolf Geiger, W. P. (1954). Eine neue Wandkarte der Klimagebiete der Erde nach W. Köppens Klassifikation (A New Wall Map of the Climatic Regions of the World According to W. Köppen's Classification). Erdkunde, 8(1), 58–61. https://doi.org/10.2307/25636021
- Sala, O. E., Parton, W. J., Joyce, L. A., & Lauenroth, W. K. (1988). Primary Production of the Central Grassland Region of the United States. Ecology, 69(1), 40–45. https://doi.org/10.2307/1943158
- Sarma, B., Chanda, S. K., & Bhuyan, M. (2017). Impact of dust accumulation on three roadside plants and their adaptive responses at National Highway 37, Assam, India. Tropical Plant Research, 4(1), 161–167. https://doi.org/10.22271/tpr.2017.v4.i1.023
- Schilstra, A. J., Strijker, D., Bettels, K., Schoot Uiterkamp, A. J. M., van Andel, J., van der Perk, J. P., & Lioe-A-Tjam, E. L. (2003). Development of an Environmental Assessment Method for Aruba. Groningen. Retrieved from www.rug.nl/ivem
- Soukup, D., Buck, B., Goossens, D., Ulery, A., McLaurin, B. T., Baron, D., & Teng, Y. (2012). Arsenic concentrations in dust emissions from wind erosion and off-road vehicles in the Nellis Dunes Recreational Area, Nevada, USA. Aeolian Research, 5, 77–89. https://doi.org/10.1016/j.aeolia.2011.11.001
- Stavi, I., Ungar, E. D., Lavee, H., & Sarah, P. (2008). Grazing-induced spatial variability of soil bulk density and content of moisture, organic carbon and calcium carbonate in a semi-arid rangeland. CATENA, 75(3), 288–296. https://doi.org/10.1016/J.CATENA.2008.07.007
- Stoffers, A. L. (1956). Studies on the Flora of Curaçao and other Caribbean Islands. Utrecht. Retrieved from http://repository.naturalis.nl/document/550089
- Stoffers, A. L., & Mansour Elassaiss, J. A. (1965). On the water relation in limestone and diabase vegetation in the Leeward Islands of the Netherlands Antilles. Acta Botanica Neerlandica, 15, 539–556. Retrieved from http://natuurtijdschriften.nl/download?type=document;docid=539435
- Sukopp, H., & Werner, P. (2011). Urban environments and vegetation. In Man's impact on vegetation (pp. 247–260). https://doi.org/10.1007/978-94-009-7269-8_19
- Thakar, B. K., & Mishra, P. C. (2010). Dust collection potential and air pollution tolerance index of tree vegetation around vedanta aluminium limited, jharsuguda. The Bioscan (Vol. 3). Retrieved from www.thebioscan.in
- Tongway, D. J., & Hindley, N. L. (2004a). LANDSCAPE FUNCTION ANALYSIS : Procedures for monitoring and assessing landscapes. With special reference to Minesites and Rangelands. Landscape. Retrieved from https://www.researchgate.net/publication/238748160_Landscape_Function_Analysis_Procedures_for_Monitoring_and_Assessing_Landscapes_-_with_Special_Reference_to_Minesites_and_Rangelands
- Tongway, D. J., & Hindley, N. L. (2004b). Landscape function analysis: a system for monitoring rangeland function. African Journal of Range & Forage Science, 21(2), 109–113. https://doi.org/10.2989/10220110409485841
- Tongway, D. J., & Hindley, N. L. (2004c). Landscape Function Analysis: Procedures for Monitoring and Assessing Landscapes - With special reference to Minesites and Rangelands. Canberra.
- van Nooren, K. (2008). Human Impact on the Vegetation of Aruba. Retrieved from http://wildaruba.org/Documents/Sympo_Presentations/wildaruba-paper-KeesNooren.pdf
- Veerbeek, B. (2016). Goats or no goats. The influence of goats on soil erosion and vegetation in Arikok National Park, Aruba. Wageningen. Retrieved from http://www.dcbd.nl/sites/www.dcbd.nl/files/documents/Veerbeek%2C B. %282016%29 Goats Aruba impact.pdf
- Versteeg, A. H., & Ruiz, A. C. (1995). Reconstructing the Brasilwood Island: the archeology and landscape of Indian Aruba. Publications of the Archaeological Museum Aruba #6.
- Vogel, T. (2017). Human induced dust in Aruba: An assessment of the transport and spatial deposition dynamics of dust from off-road driving in Aruba and the effect of driving speed and traffic density. Wageningen. Retrieved from http://www.dcbd.nl/sites/www.dcbd.nl/files/documents/Vogel_Thesis_Final.pdf
- Westermann, J. H. (1931). Aruba, with geological map. In Leidse geologische mededelingen 5 (pp. 709–714). Retrieved from https://www.repository.naturalis.nl/document/549531
- Willemsen, M. (2011). Natuurreservaat Arikok: Vegetatiekatering in her nationaal park Arikok te Aruba. Den Bosch.
- Wolfs, E., Laclé, F., Bubalo, M., van Beukering, P., & Pols, R. (2017). Cultural Ecosystem Services (CES) for Local Community in Aruba. Retrieved from http://www.dcbd.nl/sites/www.dcbd.nl/files/documents/Cultural Ecosystem Services - Local Community Aruba.pdf
- World Wildlife Fund. (n.d.). Tropical and subtropical dry broadleaf forests | Biomes | WWF. Retrieved April 5, 2019, from https://www.worldwildlife.org/biomes/tropical-and-subtropical-dry-broadleaf-forests
- WWF. (n.d.). Deserts and xeric shrublands | Biomes. Retrieved April 5, 2019, from https://www.worldwildlife.org/biomes/deserts-and-xeric-shrublands
- Zhou, Z. C., Gan, Z. T., Shangguan, Z. P., & Dong, Z. B. (2010). Effects of grazing on soil physical properties and soil erodibility in semiarid grassland of the Northern Loess Plateau (China). Catena, 82(2), 87–91. Retrieved from https://www.cabdirect.org/cabdirect/abstract/20103246605