Landscape-ecological survey of Arikok National Park, Aruba

Restoring vegetation of a dry tropical island

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Soil Physics and Land Management Group

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Abstract

Main text
Aruba invokes the image of a Caribbean tropical island paradise, with white sandy beaches and palm trees waving in the wind. The interior of the island, however is a dry place covered in thorny bushes and cacti. Arikok National Park protects a large portion of the remaining natural land of the island: steep hills with dry river beds and an area of limestone plateaus. The natural environment of Arikok is highly degraded due to a history of clear-cutting of trees and free roaming goats. It is thought that the vegetation was originally a dry tropical forest, but now it is mainly thorny woodland and shrubland, the thorny tree Hubada (Acacia tortuosa) dominating the vegetation. The park management is interested in restoring more natural vegetation to the park. To this end, it is necessary to know which vegetation types exist in the park and how they are linked to the landscape. The goal of this research project was to gain insight in the links between vegetation types and the abiotic environment in Arikok Park, and to make a landscape-ecological map combined with descriptions of the landscape-vegetation types. This can help prioritize areas which need to be protected and from where restoration can take place.

The methods consisted of preparation of relevant maps in GIS, field work and data analysis. Vegetation plots were done and abiotic parameters recorded at 100 survey points throughout the park. These points were stratified manually using a hierarchal approach with geology, landscape type and vegetation structure (canopy height and cover) as main levels of division. The resulting landscape-vegetation types were ranked on how desirable they are from a nature management perspective based on vegetation height and number of (rare) species. Correlation tests were run between vegetation parameters and abiotic factors, and the links between landscape-vegetation types and DEM-derived surface parameters like slope and wind strength were investigated.

The resulting map shows 25 landscape-vegetation units, divided into diabase, limestone, tonalite and “unconsolidated” landscape-vegetation types. Within the diabase area (which is used to refer to the Aruba Lava Formation in general), units are further divided by whether they are on windward or leeward slopes or in rooien (dry riverbeds). Limestone units are divided into higher and lower plateau (terrace) levels. The less disturbed vegetation types and the rooien proved to have the most desirable vegetation, while the desert-like coastal diabase area is least desirable. Compared to the vegetation of the national parks on Curaçao and Bonaire, however, the vegetation of Aruba is much further degraded. Brazil-dominated woodland, which was probably the original vegetation type covering most of the three islands, is still found on Curaçao and somewhat on Bonaire but is all but gone on Aruba.

There are certainly opportunities for restoration of vegetation. The Hubada-dominated woodlands of the diabase area hold potential to develop through natural succession into more diverse woodlands. On the limestone plateau, Brazil may grow back naturally from certain patches where it persists. Some of the rare tree species in the rooien may also have a chance to recover and be restored. The most important recommendation is to reduce the number goats, a precondition for any vegetation restoration. This could be achieved by removing them from small patches, preferably those areas that already contain the most desirable vegetation, or from larger portions of the park. A possible further step would be to replant (rare) tree species. This would first require further research and investigation to ensure success.

Academic annex
Annex 1, the academic annex, contains extra information about the research question, methods, results and a detailed discussion. The main research question is “Which areas of Arikok Park, Aruba offer potential

for restoration and conservation of the most desirable vegetation, and which areas run a risk of changing to the least desirable vegetation?" The correlations among vegetation structure, plant species and several abiotic factors are explored. There are weak correlations between vegetation height and cover on the one hand and soil depth and litter cover on the other hand, but erosion signs and goat influence were not correlated with the vegetation parameters. Number of species and rare species were linked to vegetation structure – taller woodland with good undergrowth had more (rare) species. Further, the landscape-vegetation types were tested for differences in the surface parameters altitude, slope, TWI and wind strength. In most cases, a higher altitude defined the more desirable vegetation among groups of similar units, while the factors slope, topographic wetness index and wind strength varied little between similar units.

When comparing this research with previous vegetation surveys, it is evident that the vegetation of Arikok Park has seen drastic changes over the past decades. There was a reduction in canopy cover and height over the second half of the 20^{th} century. However, a comparison of a 1998 air photo shows a much more bare landscape than the 2009 satellite image. The difference was caused by a Hubada takeover in the 2000's. All in all, the vegetation has degraded and many species have remained rare or become rarer over the past decades, but there are also opportunities for restoration and improvement of vegetation. When working towards restoration, there are different approaches but the goal should be a restoration of ecosystem functioning.

1. Introduction

Aruba is a small island in the Caribbean Sea located about 30 km off the coast of western Venezuela (figure 1). With its year-round hot, dry climate and sunny beaches, it is immensely popular with tourists and sees around 1.5 million visitors per year (US Department of State, 2014). Although most tourists focus on the coastline, Aruba also has something to offer on land. Arikok National Park, which covers about 18% of the island, protects some rugged hilly landscapes and cliff coasts near the sea with interesting flora, fauna, and Indian cave drawings. The vegetation of Arikok is highly degraded, due to a long history of felling trees and overgrazing by animals (Belle *et al*., 2001, Stoffers, 1956, and Van Nooren, 2008). The management of the park is interested in improving the natural value of Arikok Park through restoration of vegetation. This study focuses on describing the vegetation types and landscape factors in Arikok Park. The result is a landscape-ecological map of the park based on existing material and fieldwork, which will help towards making a new management zoning plan for the park. Additional analyses of the correlations between the biotic and abiotic environment are included in annex 1.

Figure 1 Map of Aruba, showing the location of Arikok National Park in green

2. Background situation

2.1 History

The island of Aruba has been inhabited since pre-Columbian times by Indians from the South American continent, who introduced small-scale cultivation of maize and cassava to the island (National Archeological Museum, ?). More intense human alteration occurred since the Spanish and Dutch presence. Disturbances consisted mostly of felling native trees for boat building, burning limestone, charcoal and dye production (StimAruba Tijdschrift, 1997). Goats, sheep, donkeys, cattle and horses were set free to graze the island by the Spanish and Dutch colonizers, mainly for meat production for neighboring Curaçao (National Archeological Museum, ?). In the 19th century, gold was mined and Aloe Vera was cultivated along with some food crops. Most of these activities declined in importance during the 20th century and were gradually replaced with an oil refinery (from 1929) and then tourism as the most important sources of revenue, with tourism currently providing 75% of the country's GNP. The rugged hills around Arikok and Jamanota hills remained largely uninhabited throughout this time.

Although the initial plans for a national park were developed around the 1960's, Arikok National Park was not officially established until 2000 (O. Rasmijn, pers. comm., 20/8/15). It protects about 18% of the island's surface area, mainly the rugged central hills which have been less intensely used by humans historically. The park's mission is: "Preserving, protecting and administering the present flora, fauna, landscapes, ecological habitats and cultural-historical heritage, so that present and future generations can profit from this." The park contains some popular touristic attractions such as the Conchi Natural Pool, coastal inlets with beaches and several caves with prehistoric Indian drawings. Over 130 000 visitors came to the park in 2015 (Gina Loefstok, Head Cashier Arikok Park, pers. comm., 19-1-2016), mainly for these attractions, while other parts of the park, including its many hiking trails, are much quieter.

2.2 Climate

Aruba is situated along a broad semi-arid to arid zone which extends from northern Columbia to the Orinoco delta in eastern Venezuela (Stoffers, 1965). The temperature averages 28°C year-round with little variation. The average yearly rainfall on the island is around 400mm, concentrated in the October-January rainy season, although there are large interannual variations in rainfall. Recent droughts have been the worst in years, according to a park ranger (J. Bougeon, pers. Comm., 30/8/15), while 2009-2011 were said to be exceptionally wet years. The potential evaporation is around 1600 mm/year (Grontmij and Sogreah, 1968); a more recent figure for Bonaire is 2600 mm/year (Borst and De Haas, 2005). Aruba is classified as 'BSh' (hot semi-arid) in the Köppen climate diagram.

2.3 Geology

The geology of Aruba is determined by its location along the transverse fault of the Caribbean plate moving westwards relative to the South American plate. Volcanic activity along this fault created a chain of islands and atolls stretching from Aruba eastwards to Margarita Island (Venezuela). The oldest rocks exposed on Aruba are Cretaceous magma rocks of the Aruba Lava Formation consisting of diabase (a type of basalt), volcanic tuffs and schists (Westerman, 1931 and Rijksgeologische Dienst, 1996). These rocks cover a large part of the surface in Arikok National Park. In this study, the Aruba Lava Formation is simply referred to as 'diabase'. The lavas were later intruded by a tonalite batholith complex, an intrusive igneous rock similar to diorite, found on the northwest and southwest extremes of the park and on much of the rest of the island. Both the diabase and tonalite are overlain by reef and eolianite limestones of Cenozoic age. These form terraces at different levels, the highest terraces with the oldest limestones forming sloping plateaus such as the Sero Domi formation (extreme southwest of the park) or the extensive eolianite plateaus (south-central portion of the park) while the younger terraces, found mainly in the southeast of the park are flat. A geological map of the park can be found in the digital annex.

2.4 Landscapes and soils

The landscapes of Aruba are largely determined by the underlying lithology. Previous surveys have resulted in a detailed landscape-soil map (Grontmij and Sogreah, 1968, see digital annex) which uses the three geological units as its main categories. The diabase area consists of high hills with steep dry valleys (rooien). The soils are generally shallow with low infiltration capacity, interspersed with rock exposures. The tonalite rocks are more easily weathered, resulting in deeper soils with higher infiltration capacities. The landscape consists of rolling hills with wide, shallow rooien and some large remnant boulders. The limestone terraces are mostly flat, with a rough, rocky surface with deep cracks and holes (karren) in which most of the rainwater disappears. As a result of the lack of surface runoff, there are few rooien, except on the borders of other units. Soils, consisting of weathering products of the limestone, are generally found only in the cracks and holes in the rock. Further information on the hydrology of Arikok soils is given in annex 2.

Along the coast are landscapes determined by the action of the sea. The dominant trade winds blow from the east to northeast, so the north and east sides of the island are constantly hit by waves. The coastline here is made up of low cliffs with some sandy inlets where rooien end in the sea. Some sand dunes have developed in these places. Some of the rooien end in flat, salty valleys that are tidally or seasonally submerged. There are only a few of these in the park, at Boca Prins, Dos Playa and Boca Daimari.

2.5 Vegetation

Aruba is generally covered in dry, thorny woodland and shrubland with many cacti. Several vegetation surveys have been carried out covering the whole island, the park or parts of the park. Stoffers (1956) mapped the vegetation of Aruba and the other leeward Dutch Antilles, Curaçao and Bonaire. At that time there was, as he concluded, little left of the natural vegetation. The next vegetation survey was carried out by Denters (1979a and b) in his studies on the effects of wind on vegetation and on the feasibility of a national park. He found that vegetation structure (height, cover and proportion of trees) had decreased from the 1940's to the 1970's. This trend seems to have continued in recent years. Vegetation structure in this report refers to the height and cover of the various vegetation layers: canopy, mid-level and ground stratum.

Through selective grazing of young plants, the older trees are not regenerating, and brush type vegetation develops (Denters, 1979b). The past reduction of plant cover has led to increased erosion and soil degradation (Grontmij and Sogreah, 1968 and Stoffers, 1956). This has opened the land for the overgrowth of mainly one species, Hubada. In the older studies, Hubada is not mentioned as being a dominant species. The map of Willemsen (2011) shows Hubada-dominated vegetation covering much of the park, and this is still the case today. It seems that, whether by selective grazing by goats or due to climate change, this tree has managed to spread and out-compete many other species. This has not only happened in the park but all over the island (park ranger J. Bougeon, pers. comm., 18-8-2015). An air photo composite from 1998 shows much more bare ground and less plant cover than the satellite photo from 2009. This supports the supposition that Hubada recently colonized large surface areas of the park.

3. Problem statement and objectives

It is clear that the park's vegetation has undergone drastic changes in the past decades. There are still remnants of natural vegetation (Willemsen, 2011, park rangers and O. Rasmijn, pers. comm., 8-2015), which were also mapped by previous students. If things are left to continue as they are going now, it seems that the vegetation diversity will continue to decrease. Many tree species, of which there are currently only a handful on the entire island (StimAruba Tijdschrift, 1997 and Van Belle *et al.*, 2001), are failing to regenerate (Denters, 1979b) and could go locally extinct in the near future. However, up-to-date knowledge on the state of vegetation is incomplete. The most recent vegetation survey (Willemsen, 2011) did focus on finding the link vegetation types and environmental factors, while the previous vegetation surveys are outdated. At present, there is a need for knowledge about the current state of vegetation (species, cover and structure), and about the extent to which physical factors affect the current state and (re)establishment of natural vegetation. Also, there is a need for an updated landscape–ecological map of the park.

The objective of this research was to provide the park with a new landscape-ecological map, along with descriptions of the landscape-vegetation types, their vegetation structure and composition and their interactions with their abiotic environment. This can help the board to make informed management decisions and to make a new management zoning plan, showing areas which could be set aside for nature conservation and restoration. This is important if the park's natural vegetation, constituting important habitats for Aruba's fauna and giving the landscape its natural beauty, is to be preserved. Additionally, the map is a basis on which activities such as biodiversity monitoring and impact assessment of touristic activities can be done, helping the park to balance natural and recreational functions.

4. Landscape-vegetation types

The main result of this study was the development of a landscape-ecological map. This section briefly describes the methods used to make this map, followed by a description of all the landscape-vegetation types. Section 5 will provide an analysis of how desirable these vegetation types are and compare them with the vegetation of neighboring islands. All the plant names used in this report are the Papiamento names; a table with the corresponding scientific names can be found in annex 3.

4.1 Methods

A more detailed explanation plus a justification of the methods used can be found in annex 1.

4.1.1 Preparation

The preparation consisted of collecting and studying relevant literature and collecting, scanning and digitizing existing maps. Much of the literature and some of the maps could only be found in physical form in the Wageningen library. Other literature was found in the library at Arikok or through online searches.

4.1.2 Fieldwork

The fieldwork phase started about two weeks after arrival in Aruba. First, I conducted some exploratory hikes with rangers to get to know the park and to choose fieldwork locations. The main field work consisted of doing 100 survey points, which were chosen based on various criteria. The aim was to sample locations spread widely over the whole park, and to find locations representing the full range of geological, landscape and vegetation types as apparent on the satellite image. However, I also deliberately chose points with vegetation appearing 'special', so the points cannot be considered random. At each survey point, I made a 5x5 m vegetation plot in which I recorded the height and cover of each vegetation layer (stratum) plus all the tree and shrub species. I also recorded a number of abiotic (environmental) factors at each survey point, such as erosion signs, soil depth, water repellence and goat disturbance. The level of goat disturbance was recorded at 3 levels: very low, average and very high, which translates to 5 levels used in the descriptions (see section 4.4.1 and annex 7). Further details of how the survey points were done can be found in annex 1.

4.1.3 Data analysis

After completing the field work, the survey points were grouped into clusters which became the landscape-vegetation types. This was done manually, using the geological and landscape units as the first and second level categories and the vegetation structure as a third level of subdivision. After deciding on the final legend items, the whole of Arikok park was mapped into landscape-vegetation types by manually drawing polygons around similar-looking areas on the satellite image in ArcGIS. I drove through the park with a printed preliminary version of the map to check the polygons in the field and adjust the boundaries where necessary.

4.2 Landscape-ecological map

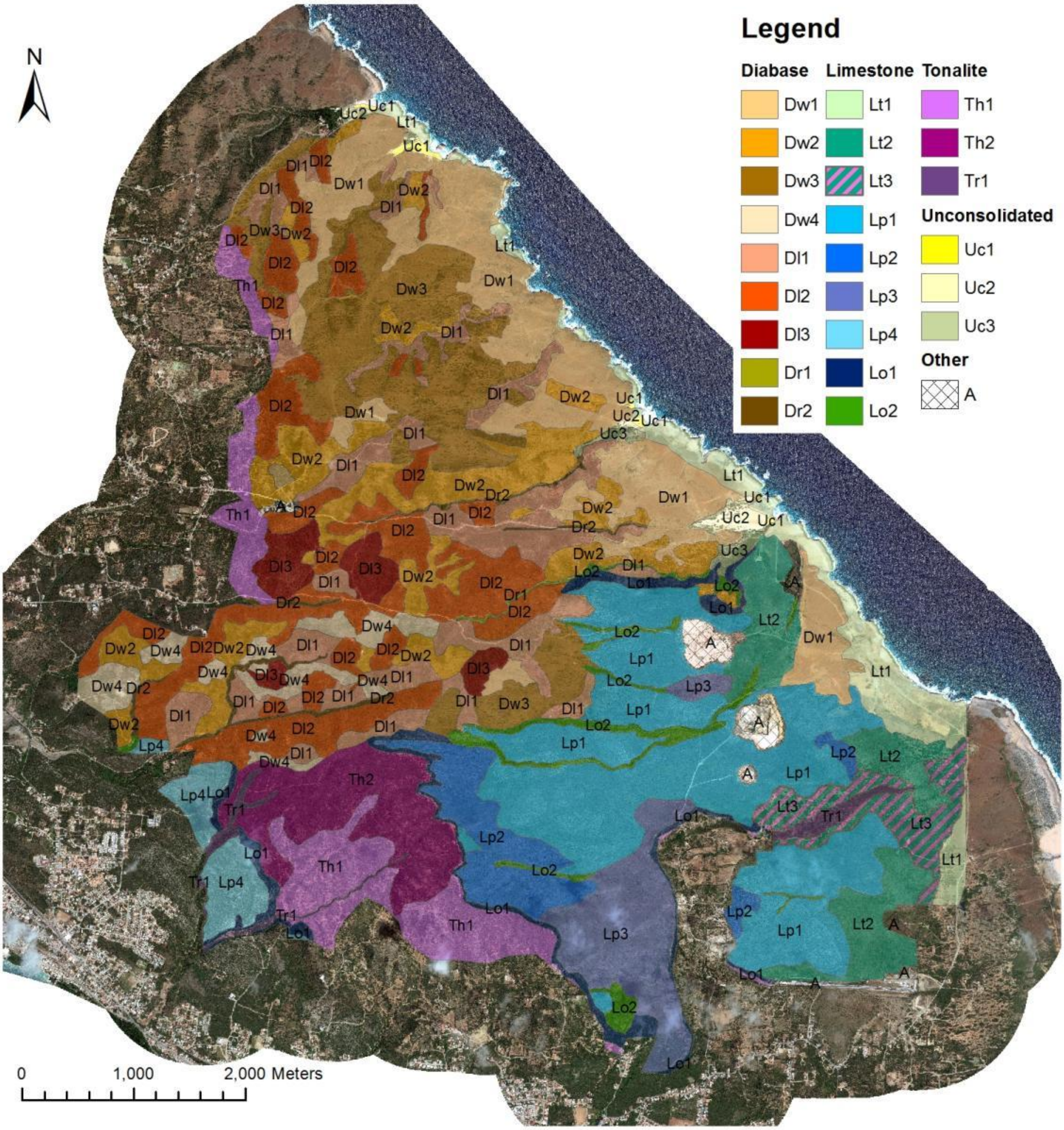


Figure 2 Landscape-ecological map of Arikok National Park, Aruba. The meanings of the legend codes are explained in the text.

4.3 Landscape-vegetation key

This section provides an identification key for the landscape-vegetation types shown in figure 2, after the example of the Dutch field guide for vegetation communities (Schaminée *et al.,* 2010). Level 1 is ordered by geological unit (Diabase, Limestone, Tonalite, Unconsolidated and Anthropogenic). Within each geological unit, the key gives distinguishing characteristics for the identification of major (landscape) groups corresponding to the small letter in the codes. Page numbers refer to the location in key level 2. Level 2 enables further determination of these landscape groups up to landscape-vegetation level.

4.3.1 Identification key level 1

D

Vegetation types on the Aruba Lava Formation (referred to simply as 'diabase'). High, steep hills and ridges and dry valleys with steep banks (rooien). Generally shallow, rocky soils with low infiltration capacity, visible erosion signs.

Dw

Vegetation on diabase slopes exposed to the dominant winds, characterized by open Hubada shrubland or woodland (<50% vegetation cover). Page 15

Dl

Vegetation on diabase slopes protected from the wind, characterized by closed Hubada woodland or closed shrubland with scattered trees (>50% vegetation cover). Page 15

Dr

Vegetation of diabase rooien, characterized by Mata di yuana and Shimarucu. Page 16

L

Vegetation types on limestone. From nearly flat coastal terraces to undulating or dipping plateaus higher up, often ending in steep escarpments, with few, shallow rooi valleys. Surface characterized by high bedrock cover, interspersed with patches of soil which can be deep in cracks and holes in the bedrock. High infiltration capacity in these cracks and almost no overland flow or erosion.

Lt

Vegetation of the coastal limestone terraces, with flat topography. Vegetation restricted to grasses and succulents close to the coast, open shrubland and low woodland further inland. Page 16

Lp

Vegetation of the limestone plateaus, farther from the coast and higher up than Lt. Undulating or dipping landscape. Open shrubland dominated by Beishi barranca or low, open woodland, often with scattered trees (mainly Mata Pisca), or dominated by Taya shrubs. Page 16

Lo

Vegetation of the limestone boundaries and drainage systems. Characterized by taller, denser woodland than Lp with a larger variety of species. Page 17

T

Vegetation types on tonalite. The tonalite area has a rolling, hilly topography, less steep than the diabase area with shallow rooien. Characterized by deep, sandy soils, often with erosion signs.

Th

Vegetation of the tonalite hills, often affected by past human cultivation. Vegetation structure and composition depends on degree of disturbance. Found in the west and southwest of the park. Page 17

Tr

Vegetation of the tonalite rooien. Shallow-sided with large boulders along and in rooi and otherwise sandy soils. Page 17

U

Vegetation types on unconsolidated material, found along the northeast coast in Arikok Park.

Uc

Coastal unconsolidated vegetation types. Deep soils consisting of sandy to loamy sediments originating from the rooien or from the sea. Vegetation depends on position in landscape, but generally consists of salt-tolerant vegetation like Fofoti, Druif and succulents. Page 17

A

Anthropogenic vegetation type, determined by human alteration. Various patches included in this unit, mostly within the limestone area. Vegetation depends on type and degree of disturbance. Page 66

4.3.2 Identification key level 2

Dw

Windward diabase hillsides

Dw1

Diabase windward 1. Nearly bare, desert-like vegetation with scattered Hubada and/or Cuihi. Page 20

Dw2

Diabase windward 2. Partly bare, open shrubland or woodland dominated by low Hubada, Cadushi and Breba. <50% canopy cover average. Page 22

Dw3

Diabase windward 3. Strips of vegetation created by Camari trees acting as a windbreak with Watapana, Huliba and Hubada growing downwind. Mostly bare ground and some shrubs in between. Page 24

Dw4

Diabase windward 4. Grassland with scattered shrubs and trees, or open woodland interspersed with grass, >30% grass cover. Page 26

Dl

Leeward diabase hillsides

Dl1

Diabase leeward 1. Low, closed Hubada woodland with few other species. <3 m tall, >50% canopy cover average. Page 28

Dl2

Diabase leeward 2. Tall, closed Hubada woodland, >3 m tall and >50% canopy cover. Sometimes dominated by Watapana, and Kedebeshi also characteristic. Often with Tuna undergrowth. Page 30

Dl3

Diabase leeward 3. Tall, open woodland (>3 m) with <50% canopy cover. A variety of trees including Kibrahacha, interspersed with shrubs (<2 m). Page 32

Dr

Diabase rooien

Dr1

Diabase rooien low. Characterized by low, open or closed Hubada woodland (<3m). Page 34

Dr2

Diabase rooien tall. Characterized by tall, generally closed Hubada woodland (>3m). Near the sea more salt-tolerant species like Oleifi and Fofoti. Page 36

Lt

Limestone terraces

Lt1

Limestone coastal terrace. Flat, coastal limestone terraces ending in cliff coast, bare or very sparsely vegetated with salt-tolerant grasses and succulents. Page 38

Lt2

Limestone middle terrace. Terrace ends in small escarpment or slope leading to another terrace level. Shrubland or open woodland vegetation dominated by Basora preto, Seida, Hubada and Cadushi. Mostly bedrock at surface. Page 40

Lt3

Limestone middle/tonalite. Same terrace level as Lt2, but found at the border of the tonalite area. Closed woodland dominated by Hubada or Cuihi. Mostly loose material at surface. Page 40

Lp

Limestone plateaus

Lp1

Limestone plateau 1. Expansive plateau with topography dipping less than 5° or undulating. Open shrubland vegetation dominated by Beishi barranca without trees or with widely scattered Mata Pisca and Camari trees, without columnar cacti (Cadushi or Breba). Page 42

Lp2

Limestone plateau 2. Topography as Lp2, but with denser vegetation. Open woodland with Beishi barranca and Flor di Sanger shrubs. Tree layer includes Mata Pisca and Palo di lechi. No columnar cacti. Page 44

Lp3

Limestone plateau 3. Topography as Lp2. Shrubland or open woodland with many columnar cacti. Page 46

Lp4

Limestone Sero Domi. Plateau remnants (Sero Domi formation) dipping steeper than 5° on average, bordered by steep escarpments. Shrubland or open woodland vegetation dominated by Taya. Page 48

Lo

Limestone boundaries and drainage elements

Lo1

Limestone escarpment. Cliff or steep slope at edge of limestone terrace or plateau, 5-40 m high. Page 50

Lo2

Limestone rooien. Dry riverbeds, often originating from outside the limestone area, sometimes gradually disappearing into the limestone plateau. Sometimes cliff edges, other times gently sloping sides. Page 52

Th

Tonalite hills

Th1

Tonalite hills disturbed. Lower tonalite hills near park borders. Low (<3 m), generally open Hubada woodland with bare areas and patches of Aloe. Page 54

Th2

Tonalite hills undisturbed. Tall (>3m), generally closed woodland with a mix of Hubada, Dabaruida, Mata di yuana and Watapana. Large old Pal'i siya blanco trees characteristic. Page 56

Tr

Tonalite rooien

Tr1

Tonalite rooien. Tall (>3m), closed woodland with a variety of species like Th2, but with more rare species such as Kiviti or Bushicuri. Sometimes characterized by overgrowth of Cordon di San Francisco (SF). Page 58

Uc

Unconsolidated coastal

Uc1

Beaches. Mostly bare sand or rocks with scattered salt-tolerant grasses and succulents, found along the shore in inlets and bays. Page 60

Uc2

Dunes. Low to tall closed Druif forest interspersed with bare sand, found on dunes inland from larger sandy beaches. Page 62

Uc3

Saline rooien. Tall to very tall (>6m on occasion) closed forest consisting of Fofoti, with some Manzaliña, Druif and other species along the edges. Page 64

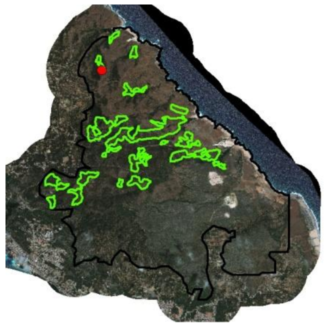
4.4 Descriptions of landscape-vegetation types

This section describes all the landscape-vegetation types, elaborating the vegetation characteristics and some environmental factors. The descriptions are ordered by geological type (diabase – limestone – tonalite – unconsolidated – anthropogenic). Within the geological categories, the types generally follow an order roughly from coastal to inland (windward to leeward, lower terrace to upper plateau) and/or from less well developed to more developed vegetation. The following page shows an example of the standard format for the descriptions (with examples).

4.4.1 Example

Name of landscape-vegetation type (landscape-vegetation code)

Example location: coordinates of an example survey point location (survey point number), and a description of how to get there.



A miniature map showing the occurrence of the landscape-vegetation type, with red dot showing example location

Occurrence: A description of where this map unit is found in the park

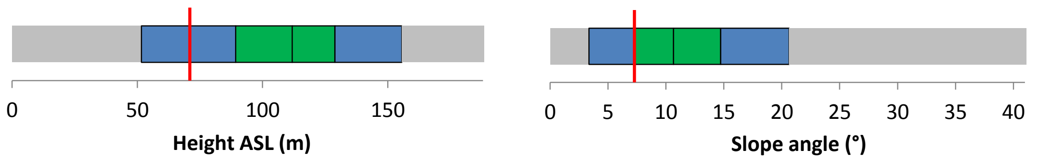
Recognition: A description of the vegetation structure and species

Ecology: Describes the environmental factors such as surface cover, substrate, soil texture, depth, water repellence and erosion. Section 3.2 of annex 1 and annex 7 explain how these were determined.

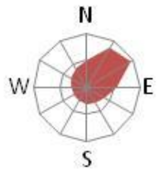
Additional ecological value: Describes any special ecological value in terms of flora and fauna.

Disturbances: Factors which negatively affect the vegetation, mostly caused by humans or goats. Goat presence (or influence) is indicated on an ordinal scale: Very low, low, average, high and very high (see annex 7).

The two bar figures below depict the altitude and slope distribution of the vegetation type. The green boxes show 25- to 75 quartiles and the black line in between the green boxes shows the median. The blue boxes show the 5- and 95 percentiles. The red line shows the median value for the whole park (all landscape-vegetation types). Example: this unit has median height of about 115 m and slope of about 11 degrees. The data for these figures and for the wind rose is derived from the digital elevation model (see annex 14).



The figure below shows the direction of exposure (aspect). Example: the red area is mostly between N and E indicating this unit is exposed to the (NE) tradewinds.



The table below shows the average height and vegetation cover for each of the vegetation layers. For grass, only the % cover is given, and for emergents, only the height (by definition, emergents have a cover of <5%).

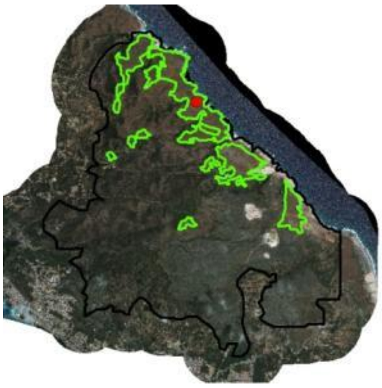
	Grass	Ground	Shrub	Canopy	Emergents
Height (m)		0.4	1	3	5
Cover (%)	<5	7	30	51	

Below is a list of species recorded in the vegetation type, plus the average percent cover in codes. The cover codes are as following: s = single observation (only for units with 5 or more survey points); 1 = <5% cover, 2 = 5-25% cover, 3 = 25-50% cover, 4 = 50-75% cover, 5 = 75-100% cover. Scientific names are given in annex 3. *marks plants recorded in <10% of survey points. † marks plants considered rare by Van Belle *et al.* (2001) with </= 200 individuals on the island (annex 4).

Species	Cover
Basora preto	2
Cadushi	1
Cordon di SF	1
Hubada	3
Huliba	1
Macubari*†	1
Tuna	1
Walishali	2

4.4.2 Diabase vegetation types

Diabase windward 1 (Dw1)



Example location: 12°30’51”N -69°55’36”W (obs 82). On road up to Arikok hill just before final steep climb, turn right onto 4WD road and immediately turn left towards Conchi. Follow this rough 4WD track almost to the coast.

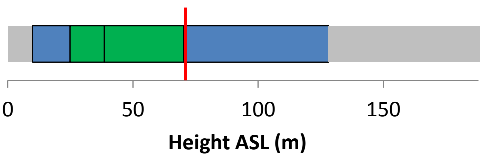
Occurrence: Large parts of the lower diabase slopes facing the ocean, plus some isolated hilltops further inland. Area 3.8 km^2.

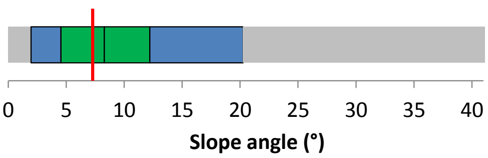
Recognition: Essentially a desert vegetation characterized by scattered Hubada and Cuihi bushes and bare, rocky ground. Poorest vegetation of the park in terms of structure, diversity and rare species. Increase in vegetation height and structural complexity from Dw1 to 3.

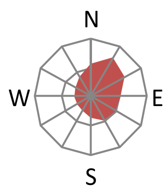
Ecology: Very shallow soils with a high percentage of loose rock cover on the ground. Severe erosion despite slopes being less steep than other windward types, probably due to lower plant cover.

Additional ecological value: None, almost no birds except some peregrine falcons.

Disturbances: High goat density, flocks of 20-30 individuals are commonly seen. Off-road tracks in whole coastal zone but mainly around Conchi, and erosion gullies can often be seen to start around these tracks.







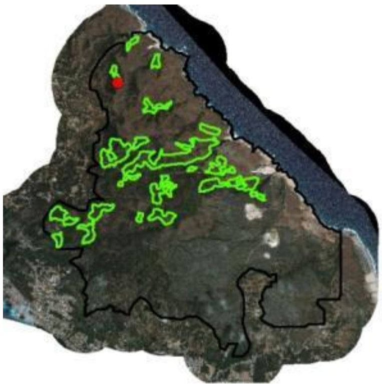
	Grass	Ground	Shrub	Canopy	Emergents
Height (m)		0.1	0.5	1	4
Cover (%)	8	12	4	41	

Species	Cover
Basora preto	1
Breba	1
Bushi	1
Cadushi	1
Camari	1
Cuihi	2
Grass	2
Hubada	3
Huliba	s
Seida	1
Shimarucu	s
Tuna	1
Watapana	1


Dw1 Erosion gullies near Dos Playa, with Hubada and Cuihi shrubs


Dw1 Near Dos Playa, with Cuihi shrubs

Diabase windward 2 (Dw2)



Example location: 12°31'7"N -69°56'45"W (obs 37). When entering the park from Shete, take the first 4WD track uphill. Example location is on the right side after 100m.

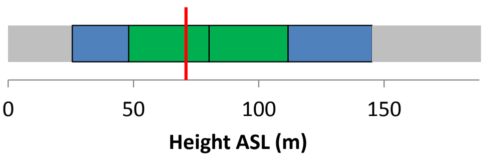
Occurrence: Just inland from the coastal Dw1 zone and scattered through the park, especially on steep, degraded hillsides. Area 2.8 km^2.

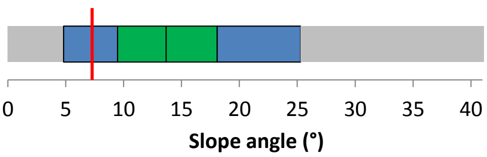
Recognition: There is a gradient towards denser vegetation going uphill and inland from Dw1, with more columnar cacti (Breba and Cadushi) and shrubs, grading into Dw2. Species diversity is low: the low tree layer is almost exclusively Hubada, with Seida, Tuna and Basora preto in the shrub layer. On the north and south facing slopes it merges with Dl1, which has higher canopy cover.

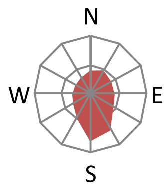
Ecology: Vegetation of higher windward diabase slopes. Soils similar to Dw1 but deeper on average with less erosion signs visible and less bedrock at the surface, despite being on steeper slopes.

Additional ecological value: None

Disturbances: Some remnants of former mining activities, high goat density.







	Grass	Ground	Shrub	Canopy	Emergents
Height (m)		0.4	0.9	1.7	5
Cover (%)	<5	17	32	49	

Species	**Cover**				
Basora preto	2	Dabaruida	1	Noni	1
Boneiro	1	Flor di sanger	1	Pal'i siya sp.*†	1
Bringamosa	1	Grass	2	Seida	1
Bushi	1	Hubada	3	Shimarucu	1
Cadushi	1	Huliba	1	Tuna	1
Camari	1	Loki-loki	1	Walishali	1
		Mata di yuana	2	Watapana	2

Dw2 Looking into Rooi Fluit, near Boca Mora, with mainly Hubada and scattered Cadushi

Dw1 Next to the road to Conchi, looking towards Boca Moro, with Hubada and Breba

Diabase windward 3 (Dw3)

Example location: 12°30’35”N -69°56’11”W (obs 54). From the top of the steep concrete section of road leading up to Arikok hill (just before the actual summit of the hill) walk to the east about 100 m.

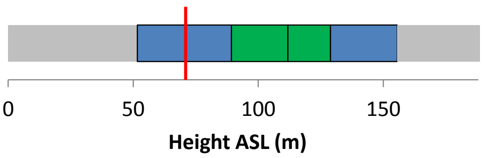
Occurrence: Large area in the higher parts of the northern diabase hills, plus some smaller portions in the center of the park (Gran Tonel). Area 3.2 km^2.

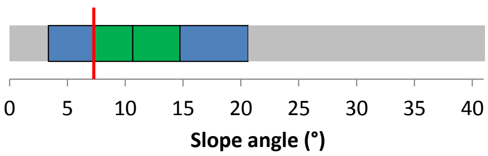
Recognition: Strips of vegetation dominated by Camari, which is characteristic for this vegetation type, with mostly bare ground in between. Camari grows in full wind, strongly bent downwind, providing shelter for Hubada, Huliba and Watapana trees to grow. Shrub layer similar to Dw2, and Breba is a common emergent. Grades into Dw1 where vegetation strips are very sparse with a lot of bare ground, but in its more developed form it approaches a climax vegetation type (see section 5.4.1).

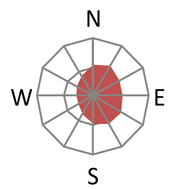
Ecology: Vegetation generally found on the highest windward diabase slopes. Soils similar to Dw2 with mostly loose rock at the surface, shallow soils and erosion signs. Soils can be water repellent.

Additional ecological value: More diversity in bird life than Dw1 and Dw2, including flycatchers and warblers, but still generally low ecological value.

Disturbances: High goat density.







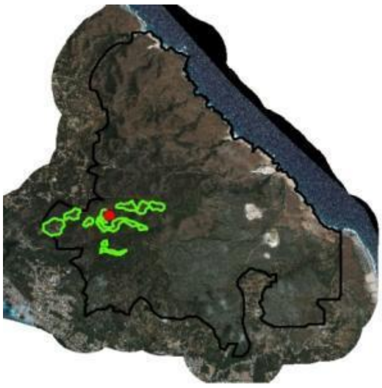
	Grass	Ground	Shrub	Canopy	Emergents
Height (m)		0.4	1	3	5
Cover (%)	<5	7	30	51	

Species	**Cover**				
Basora blanco	s	Cadushi	1	Mata pisca	1
Basora preto	2	Camari	2	Mata di yuana	s
Boneiro	s	Cuihi	2	Seida	1
Brazil	s	Grass	1	Shimarucu	1
Breba	1	Hubada	2	Tuna	1
Bushi	1	Huliba	1	Walishali	1
		Loki-loki	1	Watapana	1

Dw3 Near the summit of Arikok hill, with Camari in the middle (strongly wind-bent), and Hubada and shrubs downwind

Dw3 Two Camari trees with a Watapana in the middle, near the summit of Arikok hill

Diabase windward 4 (Dw4)



Example location: 12°29’14”N -69°56’51”W (obs 22). About halfway along the trail between Miralamar and Masiduri.

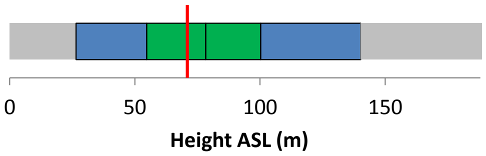
Occurrence: Broad valleys of the higher inland diabase hills. Area 0.8 km^2.

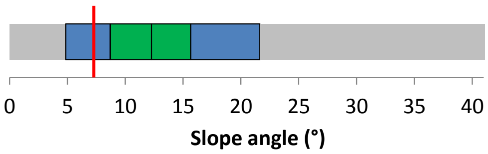
Recognition: Characterized by grasses and herbs, with low Hubada, Basora preto and Walishali. Can merge into Dl1 or Dl2 (with increasing tree cover) or Dl3 (with increasing shrub cover and scattered tall trees).

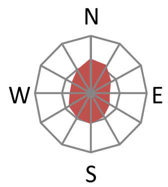
Ecology: Vegetation of broad valleys and nearby hillsides which are partly sheltered, partly windward but never as windy as the more seaward hills. Substrate is mostly metamorphosed, vertically dipping slate or schist rocks. Shallow soils with high rock and bedrock surface cover. Wind erosion occurs.

Additional ecological value: Seems to be a preferred area for Cascabel (Crotalus unicolor) (two were observed in this vegetation type at the edge of Dl2).

Disturbances: Goats seem to have a low influence, though this may be higher in the wet season.







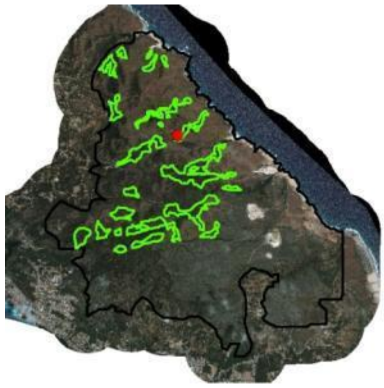
	Grass	Ground	Shrub	Canopy	Emergents
Height (m)		0.3	1.3		5.5
Cover (%)	40	55	28		

Species	**Cover**
Basora preto	1
Betonica	1
Boneiro	1
Bringamosa	1
Bushi	1
Cadushi	1
Cuihi	1
Dabaruida	1
Grass	3
Hubada	3
Huliba	1
Kedebeshi†	1
Loki-loki	1
Shimarucu	1
Tarabara	1
Tuna	1
Walishali	2
Watapana	1

Dw4 Grassy trail near Wela Mina, with low Cuihi, Hubada and Cadushi

Dw4 Grassy hillside just south of Jamanota hill looking west into rooi Taki, showing slate rocks, with low Hubada shrubs in background

Diabase leeward 1 (Dl1)



Example location: 12°30’23”N -69°55’54”W (obs 55). Turn right just before the steep concrete section on the road up to Arikok hill onto a 4WD track and continue straight at the next split. Example location is after 700m on the left hand side.

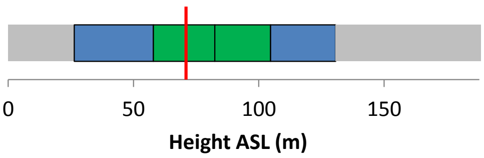
Occurrence: Patches throughout the diabase area, often on north and south facing slopes in the higher hills and in the transition from windward to leeward vegetation. Area 2.6 km^2.

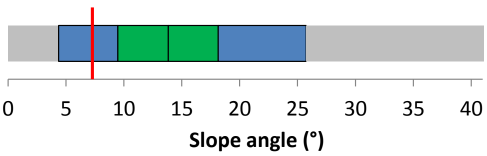
Recognition: Low Hubada-dominated woodland with a few other species such as Cuihi, Huliba, Camari and Cadushi. Light undergrowth with Loki-loki, Walishali, Basora preto and Tuna. Low species diversity. Increasing vegetation structural complexity, in terms of canopy and mid-stratum height and cover, and plant species diversity from Dl1 to 3.

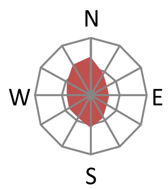
Ecology: Soils generally deeper than in the windward vegetation types but still very rocky, and erosion signs can be severe.

Additional ecological value: None

Disturbances: High goat density





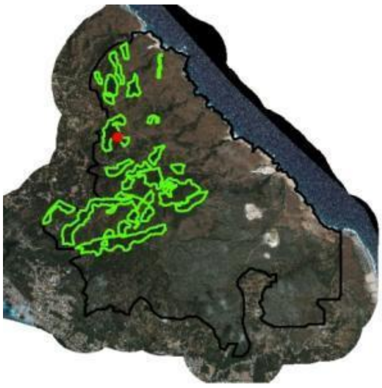


	Grass	Ground	Shrub	Canopy	Emergents
Height (m)		0.4	1.5	2.3	
Cover (%)		5	13	63	

Species	**Cover**
Basora preto	2
Boneiro	1
Bushi	1
Cadushi	1
Camari	1
Cuihi	1
Hubada	3
Huliba	1
Loki-loki	2
Mata di yuana	2
Seida	1
Shimarucu	1
Tuna	1
Walishali	1
Watapana	2

Dl1 Low Hubada woodland along the road up to Arikok hill, with Tuna undergrowth and Cadushi in the background

Diabase leeward 2 (Dl2)



Example location: 12°30’20”N -69°56’44”W (obs). From the top of Arikok hill, walk west for about 400 m, descending into thick, low Hubada which quickly becomes taller and more varied.

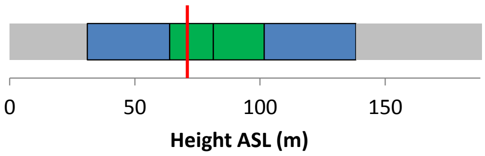
Occurrence: Leeward areas of the higher hills from the steep rooi sides near the coast in the northern diabase hills to large areas further inland. Area 3.5 km^2.

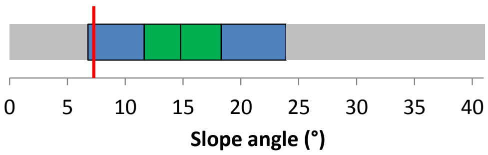
Recognition: Tall, closed Hubada woodland with a variety of other trees such as Boneiro, Cuihi, Dabaruida, Mata di yuana, Huliba, Kedebeshi, Shimarucu and Watapana, depending on location. Columnar cacti (mainly Cadushi) always present. Open understory with Tuna and other common species. Watapana sometimes dominant, often alongside Kedebeshi; old trees of these species often contain epiphytes.

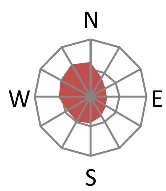
Ecology: Vegetation of leeward diabase slopes with low bedrock and loose rock cover on the surface and slightly deeper soils than in windward vegetation types despite steep slopes. Erosion signs are still present. Soils loamy sand or sandy loam with many organic matter fragments making them strongly water repellent.

Additional ecological value: High species diversity can be found in the lee of Jamanota hill. Several rare trees and plants found, including two *Tillandsia* epiphytes: Barba di Cadushi and the larger Yerba di cabai, both found nowhere else (though possible in Dl3). Many bird species common including hummingbirds, flycatchers, orioles, pigeons and doves.

Disturbances: Goat presence high almost everywhere. In some places disturbances from former mining activities, in other places trash from nearby roads.







	Grass	Ground	Shrub	Canopy	Emergents
Height (m)		0.8	1.5	3.9	7.1
Cover (%)		14	25	75	

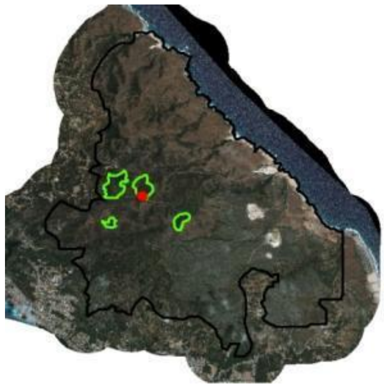
Species	Cover				
Basora blanco	1	Cadushi	1	Huliba	1
Basora preto	1	Camari	1	Huliba macho*†	s
Betonica	s	Cordon di SF	1	Kedebeshi†	1
Boneiro	1	Cucuisa	s	Kibrahacha*	s
Brazil*†	s	Cuihi	1	Loki-loki	2
Breba	1	Dabaruida	1	Macubari*†	s
Bringamosa	1	Flor di sanger	1	Mata pisca	s
Bushi	1	Grass	1	Mata di yuana	1
		Hubada	3	Pal’i siya blanco†	s

Pal'i siya sp.*†	s	Tarabara	1	Watapana	2
Seida	1	Tuna	2	Wayaca	s
Shimarucu	1	Walishali	1	Yerba di cabai	s

Dl2 Hubada woodland with dense Tuna undergrowth and Dabaruida in the foreground, near Rooi Prins.

Dl2 Yerba di cabai epiphytes in old Kedebeshi, along trail leading up to Jamanota hill.

Diabase leeward 3 (Dl3)



Example location: 12°29’31”N -69°56’24”W (obs 17). From the road intersection at the base of Jamanota hill, walk about 100 m northeast.

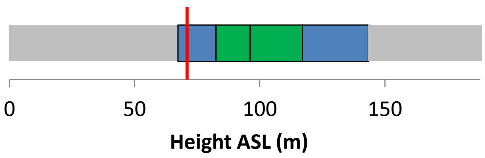
Occurrence: In the lee of a few higher inland hills. Area 0.6 km^2.

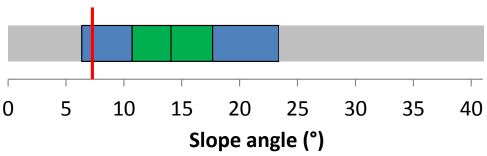
Recognition: Taller and more open woodland than Dl2. Tree species similar to Dl2, but Hubada is less dominant. Kibrahacha, Watapana, Pal’i siya blanco, Kedebeshi and Cawara blanco are characteristic. Undergrowth is tall and quite dense compared to Dl2, with mainly Basora preto, Walishali and Flor di Sanger. Lower to the ground are many herbs which proliferate in the rainy season. Some patches with monumentally tall, old Cadushi plants. Sometimes transitions to an open shrubland with few trees. Difficult to distinguish from Dl2 on satellite image and in the field at a distance.

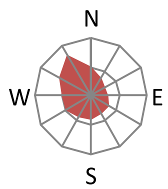
Ecology: Vegetation of highest leeward hillsides, with low loose rock and bedrock cover. Soils quite deep, loamy sand to sandy loam with many organic fragments, and strongly water repellent.

Additional ecological value: High species diversity; many more would certainly be found in rainy season. Old Cadushi plants important for many animals including nesting spots for Caracaras.

Disturbances: Old mines nearby; average goat presence.







	Grass	Ground	Shrub	Canopy	Emergents
Height (m)		0.5	2	4.4	7.8
Cover (%)	<5	10	35	48	

Species	**Cover**
Basora blanco	1
Basora preto	2
Betonica	1
Boneiro	1
Bringamosa	1
Bushi	1
Cadushi	2
Cawara blanco*†	2
Cuihi	1
Dabaruida	2
Flor di sanger	1
Grass	1
Hubada	2
Huliba	1
Kedebeshi†	1
Kibrahacha*	2
Kiviti*†	1
Loki-loki	1
Macubari*†	1
Maripampun	1
Pal’i siya blanco†	1
Seida	1
Shimarucu	1
Tarabara	1
Tuna	2
Walishali	2
Watapana	2

Dl3 Small rooi between Gran Tonel and Jamanota hill, with Hubada (thorny, bottom right), Mata di yuana (whitish, foreground), Dabaruida (light greenish glow, center left), single Huliba (small dark green, center right), Watapana (green, background) and numerous Cadushi

Diabase rooien low (Dr1)

Example location: 12°31’06”N -69°56’33”W (obs 36). When crossing Rooi Fluit on the dirt road from Shete to Conchi, walk left into the rooi for about 400 m.

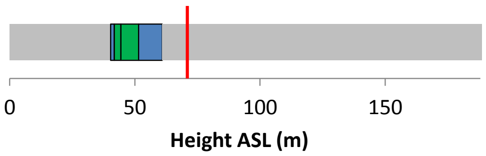
Occurrence: Section of upstream Rooi Tambu (mapped). Also upstream sections of other large rooien plus many small rooien, especially in the northern diabase area. These are not mapped because of their small size, but absorbed into neighboring vegetation types. Mapped area 0.03 km^2 (3 ha).

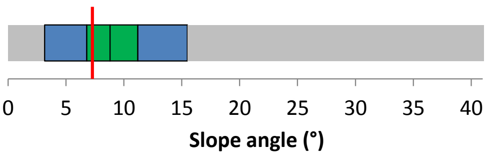
Recognition: Low Hubada-dominated woodland. Often simply a continuation of the vegetation on the slopes (Dl1 or Dw2), though a few species which require more moisture (Mata di yuana and Shimarucu) are characteristic. Vegetation in the rooi beds itself often restricted to a few weeds and shrubs; the trees are found along the edges of the rooien. Some old Fofoti trees found near the coast, e.g. in Rooi Bolongfa.

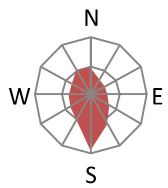
Ecology: Vegetation of narrow, steep-sided rooien, usually with steep longitudinal sections. Surface quite rocky; soils moderately deep, loamy sand in rooi edges and sandy or gravelly in rooi bed itself.

Additional ecological value: Small seasonal pools form breeding habitat for land crabs and other invertebrates. Far fewer birds than in Dr2.

Disturbances: Goat influence high.







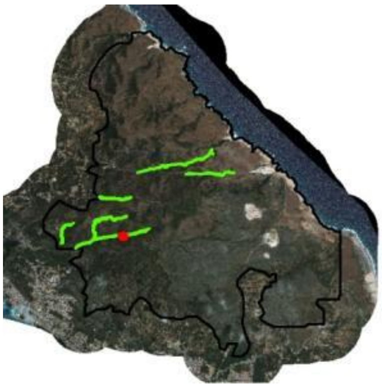
	Grass	Ground	Shrub	Canopy	Emergents
Height (m)		0.6	1.5	2.6	4.3
Cover (%)		4	15	80	

Species	**Cover**				
Basora blanco	1	Cuihi	1	Palo di lechi	1
Basora preto	2	Dabaruida	1	Seida	1
Boneiro	1	Hubada	3	Shimarucu	1
Bringamosa	1	Huliba	1	Tuna	1
Bushi	1	Kedebeshi†	1	Walishali	1
Cadushi	1	Loki-loki	1	Watapana	2
		Mata di yuana	2	Yerba di sali	1

Dr1 Low Hubada in Rooi Bolongfa

Dr1 Old Fofoti tree in Rooi Calcoriti

Diabase rooien tall (Dr2)



Example location: 12°28’57”N -69°56’40”W (obs 84). From Masiduri, walk down rooi Masiduri and turn left into Rooi Taki, walking up this rooi for 750 m. Alternatively, enter Rooi Taki from Spaans Lagoen.

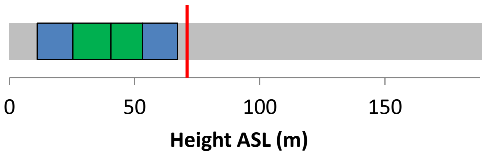
Occurrence: Larger rooien throughout higher hills of diabase landscape. Area 0.1 km^2.

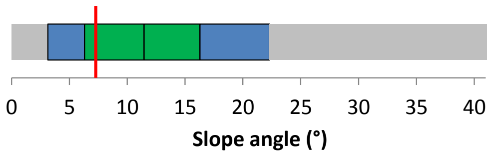
Recognition: More structurally developed than Dr1 with taller trees and more undergrowth. Hubada is dominant but many other species such as Cawara blanco, Kedebeshi, Mata di yuana, Pal’i siya blanco, Shimarucu and Wayaca are found. Macubari, otherwise uncommon, was found here in 3 out of 11 survey points. Various grasses, weeds and low shrubs often grow on the sandy deposition banks, such as Basora blanco, Yerba sali and Tarabara, plus many others not identified. Fofoti and Oleifi trees found in certain parts of the rooien, often close to mouths but also further inland, indicating saline conditions. Examples are Rooi Tambu and Rooi Taki.

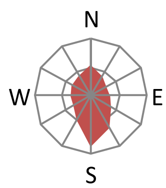
Ecology: Vegetation of larger diabase rooien, usually with steep walls but less steep longitudinal sections than Dr1. Sandy soils with a lot of gravel in rooi bed, locally with sandy deposition banks. Nearby flat areas and banks and often have deep loamy soil.

Additional ecological value: Many bird species including hummingbirds, flycatchers, orioles, and Shoco (Athene culicularia arubensis). Also iguanas observed.

Disturbances: Average goats impact (less than in Dr1), though it varies from rooi to rooi. In Rooi Tambu, goats gather in large numbers to sleep and drink, while Rooi Masiduri seems to have almost no goats. The invasive species Cordon di SF threatens natural vegetation. In some rooien (parts of Taki, Masiduri, Tambu), it has completely overgrown native vegetation.







	Grass	Ground	Shrub	Canopy	Emergents
Height (m)		0.5	1.3	4.4	7
Cover (%)	<5	11	29	79	

Species	**Cover**				
Basora blanco	1	Cadushi	1	Flor di sanger	1
Basora preto	1	Calbas	1	Fofoti*	s
Betonica	2	Cawara blanco*†	1	Grass	s
Boneiro	1	Cordon di SF	2	Hubada	2
Bringamosa	s	Cuihi	2	Huliba	1
Bushi	1	Curahout*†	s	Cadushi di colebra	1
		Dabaruida	1	Kedebeshi†	1

Kibrahacha*	s	Oleifi*	s	Tarabara	1
Loki-loki	1	Pal'i siya blanco†	1	Tuna	2
Macubari*†	1	Pal'i siya cora*†	s	Walishali	1
Mata combles*†	s	Seida	1	Watapana	1
Mata di yuana	2	Shimarucu	1	Wayaca	1

Dr2 Looking into Rooi Taki with Hubada, Cadushi, Boneiro and Tuna mainly showing

Dr2 Curahout trees (brown seed pods) and Breba with Basora preto, Tuna and Cadushi in foreground, along the edge of Rooi Prins

4.4.3 Limestone vegetation types

Limestone coastal terrace (Lt1)

Example location: 12°29’4”N -69°53’47” E (obs 47), east of road between Fontein and Vader Piet.

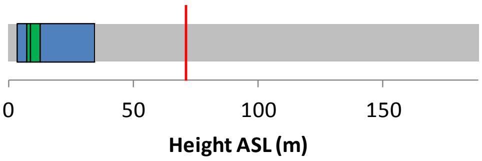
Occurrence: A thin strip along the northeast coast of Arikok, absent where diabase forms the coastline. Area 1.4 km^2.

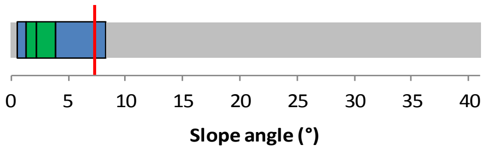
Recognition: Salt tolerant grasses with scattered low Hubada shrubs, in some places various kinds of succulents such as Banana di rif. Low species diversity.

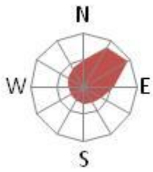
Ecology: Vegetation of coastal terraces on very shallow soils with mostly bare rock and sand, in some areas thin cover of diabase rubble. Surface pavements of gravel occur overlying silty material.

Additional ecological value: Breeding area for Least Terns (observed at Boca Prins); occasional Black-necked Stilts visit and probably rabbits. Some succulents and grass species are probably specific to this landscape-vegetation type.

Disturbances: Off-road driving causing wind erosion, notably in between Boca Prins and Dos Playa. Low goat presence, though this may be much higher in the wet season when the grazing is better.







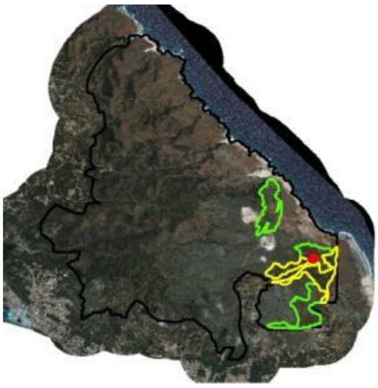
	Grass	Ground	Shrub	Canopy	Emergents
Height	0.1		0.3		
Cover	25-50		3		

Species	**Cover**				
Basora preto	1	Grass	3	Unknown succulents	1
Druif*	1	Hubada	1		
		Tuna	1		


Lt1 Coastal limestone plateau near Dos Playa with diabase outcrop in background, salt-tolerant grass in foreground.


Lt1 Coastal limestone plateau near Dos Playa showing scattered salt-tolerant grasses

Limestone middle terrace (Lt2) and Limestone middle/tonalite (Lt3)



Example location: 12°28’42”N -69°53’52”W, (obs 43), west of road between Fontein and Vader Piet.

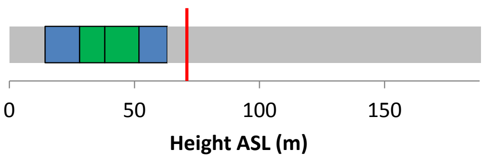
Occurrence: A few sizable terraces in the southeast corner of the park near Vader Piet. Area 1.5 km^2 (2.3 km^2 including Lt3 shown in yellow).

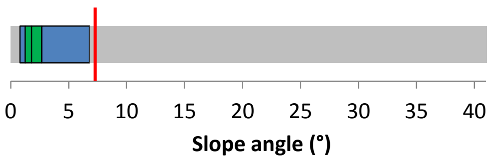
Recognition: More disturbed than limestone plateau vegetation, with considerable variation in structure and composition. Open or closed shrubland with Basora preto, Walishali, Flor di Sanger and Seida. (These four species are less favoured by goats or are dispersed by them and are thus found commonly throughout the park, especially in more disturbed landscapes.) Scattered Hubada and Cadushi in tree layer. The presence of Beishi barranca points to a relation with the less disturbed limestone vegetation types. Can deteriorate into a more bare, open landscape as seen closer to the coast. Lt3 is a variation of Lt2 with taller woodland (Hubada and Cuihi). Vegetation information below is for Lt2.

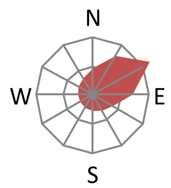
Ecology: Vegetation of middle limestone terraces between coastal terrace and higher plateaus; does not strictly map one on one with the middle terraces from the landscape-soil map. As with the higher limestone plateaus, ground cover consists mostly of litter and bedrock (few loose rocks or bare soil). Soil can be deep in pockets and is usually sandy or silty loam. Erosion is virtually non-existent, as in all limestone areas. Lt3 has deeper soils, probably due to deposition from Rooi Balaster, and borders the tonalite landscape.

Additional ecological value: none

Disturbances: Very high goat presence. Remnants of stone walls point to historic use as agricultural and/or grazing areas. A large trash dump is found southwest of the Vader Piet entrance, just on the park border (turn right on small dirt road just after exiting the park from the Vader Piet entrance).





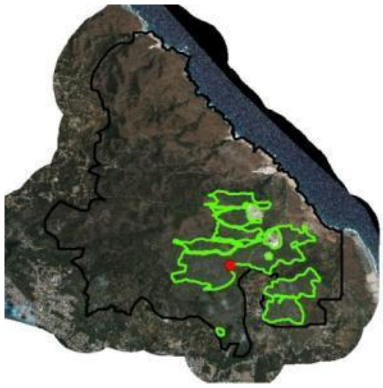


	Grass	Ground	Shrub	Canopy	Emergents
Height		0.3	0.8	1.8	5
Cover		3	37	39	

Species	**Cover**				
Basora preto	2	Calbas*	s	Mata di yuana	s
Beishi barranca	1	Cuihi	1	Seida	2
Breba	s	Flor di sanger	1	Tuna	1
Bringamosa	1	Grass	1	Walishali	1
Bushi	s	Hubada	3	Wayaca	s
Cadushi	1	Huliba	s		
		Katunbum	s		

Lt2 Middle limestone plateau next to trash dump, near Vader Piet, southeast corner of the park, showing mostly Basora preto and Beishi barranca in foreground, and Hubada and Cadushi in mid-to background

Limestone plateau 1 (Lp1)



Example location: 12°29’20”N -69°54’49”W (obs 60), west of the dirt road leading into the park north of Butucu. Alternatively, climb onto the limestone plateau at the Barbacoa dam and walk southeast for 1.5 km, crossing Rooi Thomas.

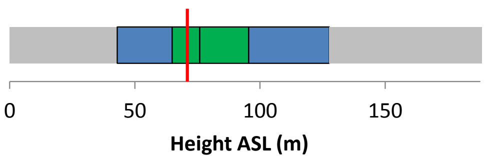
Occurrence: Largest part of high limestone plateau in south of park. Area 5.1 km^2.

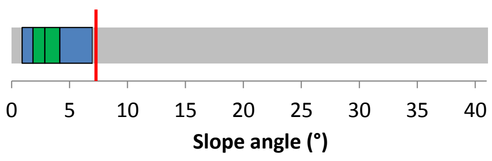
Recognition: Low shrubland with scattered trees. Dominated by Beishi barranca and Basora preto, with frequent Seida, Tuna and Walishali in the shrub layer. Palo cayente is also characteristic. Trees mostly small, wind-bent Mata Pisca, with occasional Hubada or other species. Brazil sometimes found growing low to the ground, indicating it may have been a dominant tree in the past.

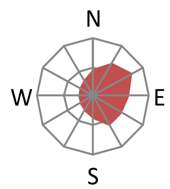
Ecology: Vegetation of the lithified sand dunes and reef limestones, with topography slightly dipping towards the northeast. Solid limestone bedrock covering 50% of surface, with karren (solution) features. Soils sand to loamy sand, deep in pockets and cracks in limestone.

Additional ecological value: Largest area of occurrence for species characteristic of limestone, hardly found anywhere else in the park, such as Palo cayente, Mata pisca and Palo di lechi.

Disturbances: High goat presence, though it varies over the large plateau area.







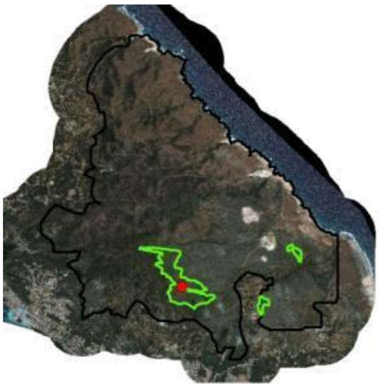
	Grass	Ground	Shrub	Canopy	Emergents
Height		0.1	1		3
Cover		5	59		

Species	**Cover**				
Basora preto	2	Grass	1	Seida	2
Beishi barranca	3	Hubada	1	Taya	s
Brazil*†	1	Huliba	1	Tuna	1
Bushi	s	Loki-loki	s	Walishali	1
Cadushi	1	Mata combles*	s	Watapana	s
Camari	s	Mata pisca	1	Wayaca	s
Dabaruida	s	Noni	1	Yerba di sali	s
Flor di sanger	1	Palo di lechi†	1		
		Palo cayente	2		

Lp1 Southern upper limestone plateau near Palo Marga showing open Beishi barranca shrubland with Basora preto and a few distant Mata Pisca in background

Lp1 Western upper limestone plateau showing Palo di lechi in foreground, a single Mata Pisca tree, Palo cayente (green shrubs), Beishi barranca, Basora preto and a single Tuna

Limestone plateau 2 (Lp2)



Example location: 12°28’15”N -69°55’45”W (obs 96), next to rooi Mahawa. Walk south from Barbacoa dam, west from Butucu or northeast from Awa Marga.

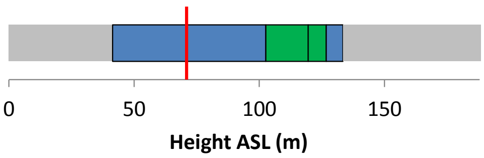
Occurrence: Highest parts of the upper limestone plateau at its western edge bordering the tonalite area, with small pockets elsewhere. Area 1.2 km^2.

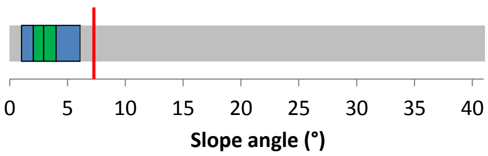
Recognition: Quite similar to Lp1 except for the tree layer, which has a higher cover and is more varied than in Lp1. Camari, Dabaruida, Huliba and Palo di lechi commonly found. Brazil occasionally found along with Huñagato, an even rarer species. Small patch of woodland in the western limestone plateau near Drumidera quarry consists of Curahout and Wayaca.

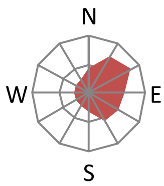
Ecology: Mostly similar to Lp1. Soils are sometimes water repellent.

Additional ecological value: Least disturbed limestone vegetation, contains some uncommon or rare species. Important potential for dispersal of species to the nearby limestone areas. One Cascabel (Crotalis unicolor) seen during field work in this unit.

Disturbances: Goats seem to have a low presence.







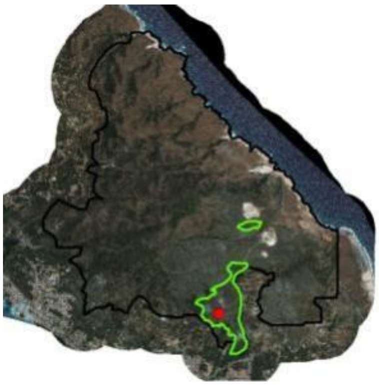
	Grass	Ground	Shrub	Canopy	Emergents
Height (m)		0.2	1	2.5	
Cover (%)	<5	3	73	23	

Species	Cover				
Basora preto	2	Dabaruida	1	Mata di yuana	1
Beishi barranca	2	Flor di sanger	2	Noni	1
Boneiro	2	Giron*†	1	Palo di lechi†	2
Brazil*†	1	Grass	1	Palo cayente	1
Bringamosa	1	Hubada	1	Seida	2
Bushi	1	Huliba	1	Tuna	1
Cadushi	1	Huñagato*†	1	Walishali	3
Camari	1	Loki-loki	2		
		Mata pisca	2		

Lp2 Old Brazil tree on western upper limestone plateau surrounded by Basora preto, Flor di sanger and Beishi barranca shrubs

Lp2 Open Mata Pisca woodland near Rooi Mahawa with Beishi barranca and other shrubs

Limestone plateau 3 (Lp3)



Example location: 12°27’50”N -69°55’15”W (obs 76). Walk across the limestone plateau south from Barbacoa dam, west from Butucu or northeast from a small entrance on the outskirts of Brazil, Savaneta.

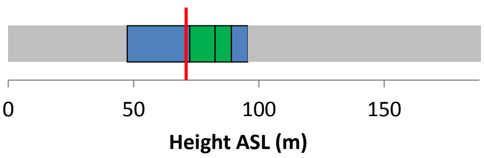
Occurrence: Large area in the southern tip of the central limestone plateau. Area 1.4 km^2.

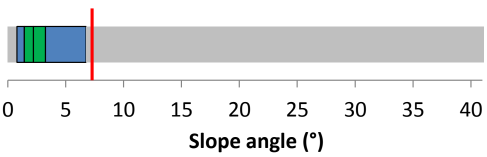
Recognition: Similar to Lp1 but with more trees, and Cadushi cacti common and conspicuous as opposed to Lp1 and Lp2. Tree species include Hubada, Huliba, Dabaruida, Cuihi and Boneiro. Shrub composition very similar to Lt2, but Lp3 has higher tree cover and larger diversity of tree species.

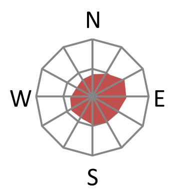
Ecology: Vegetation found mainly on the lower parts of the upper limestone plateau. Surface cover has a higher percentage of soil and less bedrock, possibly because of accumulation of weathering products from the higher parts of the plateau. Soils deeper than in Lp1 and Lp2 and finer in texture (loam to loamy sand).

Additional ecological value: A few rare species common here (Palo di bonchi), may have been propagated by humans for use in property borders.

Disturbances: More disturbed than Lp1 and 2, indicated by the presence of many stone walls and Aloe plants. Average goat presence. Marked as ‘former agricultural land’ by Roest (1995), see annex 1 section 4.4.







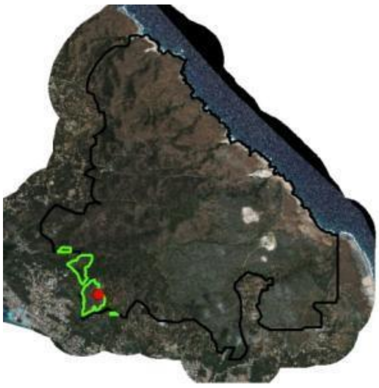
	Grass	Ground	Shrub	Canopy	Emergents
Height (m)		0.3	1.2	2.1	5.8
Cover (%)		27	63	36	

Species	**Cover**				
Aloe	1	Dabaruida	1	Palo di lechi†	1
Basora preto	2	Flor di sanger	2	Pal’i siya blanco	1
Beishi barranca	1	Grass	1	Palo cayente	1
Boneiro	1	Hubada	2	Seida	2
Breba	1	Huliba	1	Taya	1
Bushi	1	Loki-loki	1	Tuna	2
Cadushi	1	Mata pisca	1	Walishali	2
Cuihi	2	Mata di yuana	1	Wayaca	1
		Palo di bonchi*†	1		

Lp3 Old stone wall with Flor di sanger, Basora preto, Tuna, Walishali shrubs, prominent Palo di bonchi trees and Cadushi in background

Lp3 Southern limestone plateau looking southeast; Butucu escarpment on left. Beishi barranca, Basora preto and Hubada dominate with many Cadushi in background

Limestone Sero Domi (Lp4)



Example location: 12°28’10”N ° -69°56’59”W (obs 100), in the middle of Isla plateau.

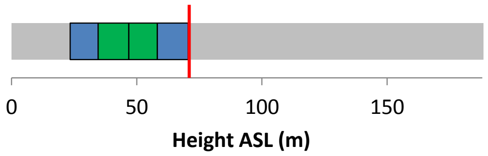
Occurrence: Small parts of the southwest corner of the park. Area 0.6 km^2.

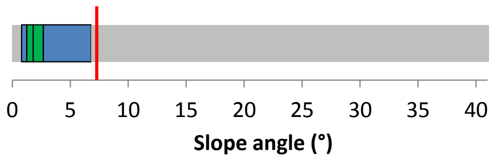
Recognition: Generally open shrubland with scattered trees and patches of denser trees. Dominant species Hubada (tree layer) and Taya (shrub layer), which is barely found in other vegetation types and gives characteristic yellowish glow in the dry season. Other common trees: Cuihi, Dabaruida, Mata di yuana and Wayaca; common shrubs: Loki-loki, Seida and Bringamosa. Species diversity higher than in the other limestone areas, but many are common weedy species found throughout the park.

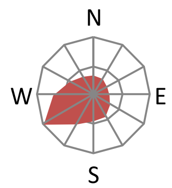
Ecology: Vegetation of Sero Domi formation, limestone terrace remnants sloping >5° towards the southwest coast. Bedrock or loose limestone rubble covers around 70% of the surface. Shallow, loamy sandy soils.

Additional ecological value: Some rare plant species along the edge of the Sero Domi terraces (Wayaca shimaron, Pal’i siya cora) presenting an opportunity for vegetation conservation and restoration. These places are close to the edge of the area mapped as Limestone escarpment (Lo1).

Disturbances: Many stone wall remnants, aloe plants and the exotic plant Cordon di SF pointing to past disturbance. High goat presence.





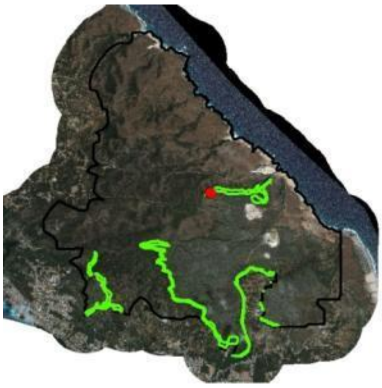


	Grass	Ground	Shrub	Canopy	Emergents
Height		0.4	1.3	2.5	4
Cover	1.5	18	65	33	

Species	**Cover**				
Aloe	1	Cuco di Indjan	1	Palo di lechi	1
Basora preto	2	Cuihi	1	Pal’i siya blanco†	1
Betonica	1	Dabaruida	2	Seida	2
Boneiro	1	Grass	2	Shimarucu	1
Bringamosa	1	Hubada	2	Taya	4
Bushi	1	Huliba	1	Tuna	1
Cadushi	1	Loki-loki	1	Walishali	1
Cordon di SF	2	Mata di yuana	1	Watapana	1
		Noni	1	Wayaca	1

Lp4 View over Isla, with Taya shrubs, Hubada mid-right and lone Wayaca tree in background near escarpment; the Hooiberg can be seen on the left in the distance

Limestone escarpment (Lo1)



Example location: 12°29'21"N -69°55'4"W (obs 30). Walk east in Rooi Prins from the starting point at the road crossing for about 1 km, then climb the escarpment slope to the right.

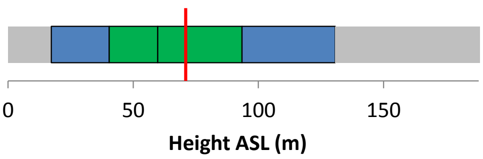
Occurrence: Thin strip around the edge of the limestone plateaus where they end in an escarpment. Area 0.8 km^2.

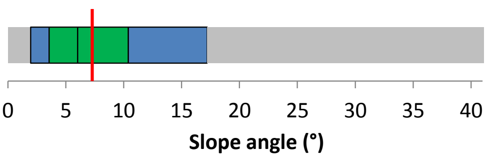
Recognition: Variable vegetation which depends on orientation to the wind and underlying rock formation (diabase or tonalite), but generally tall woodland where sheltered from the wind. Dominant species Mata di yuana and Hubada, with many other common trees occurring. Some species specific to the escarpment area such as Kiviti; Pal'i siya blanco and Wayaca also characteristic in the landscape.

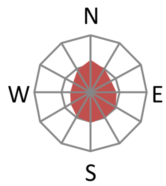
Ecology: Height of escarpment from 5m in most places to around 40m along Rooi Prins and around the Sero Domi terrace remnants (Isla). Steep slopes and rugged topography. On the border of major geological units, so lithology is a mix of limestone and diabase or tonalite. Surface cover a mix of litter, soil and loose rocks, interspersed with large boulders. Generally deep, (loamy) sandy soils in between the boulders.

Additional ecological value: Some rare tree species found. Small caves and rock overhangs may shelter sleeping bats. Old Cadushi with Warawara (Caracara cheriway) nest was observed.

Disturbances: Goat presence high: large numbers of goats use sheltered areas, rock overhangs and small caves to sleep.







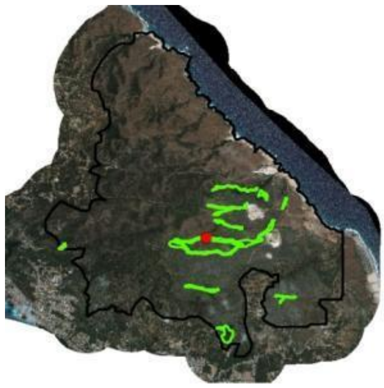
	Grass	Ground	Shrub	Canopy	Emergents
Height (m)		0.5	1.3	4.2	10
Cover (%)	<5	22	25	60	

Species	**Cover**	Cordon di SF	1	Mata di yuana	3
Basora blanco	1	Cuco di Indjan	1	Noni	1
Basora preto	2	Cuihi	1	Pal'i siya blanco†	1
Beishi barranca	1	Dabaruida	2	Seida	1
Betonica	1	Flor di sanger	1	Taya	1
Boneiro	1	Grass	2	Tuna	1
Bringamosa	1	Hubada	1	Walishali	2
Bushi	1	Huliba	1	Watapana	1
Cadushi	2	Loki-loki	1	Wayaca	1
Camari	1	Maripampun	1		

Lo1 Looking east from the limestone escarpment above Rooi Barbacoa, with Beishi barranca, Basora preto and Mata pisca (in the distance) on the plateau, Cadushi, Hubada, Boneiro and Mata di yuana to the left.

Lo1 Limestone escarpment next to Rooi Lamunchi opposite Isla, with Cadushi, Huliba and a prominent Pal'i siya cora on left along with various shrubs. The rooi is dominated by Cuihi, Hubada and Cordon di SF.

Limestone rooien (Lo2)



Example location: 12°28'57"N -69°55'30"W (obs 28), next to the Rooi Barbacoa dam.

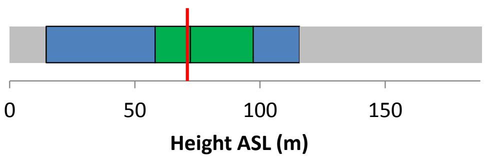
Occurrence: Throughout the limestone area and along its edges. Area 0.6 km^2.

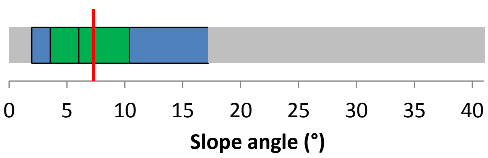
Recognition: Tall, open or closed woodland in sheltered areas while the shallow rooien are more exposed to the wind and contain low woodland or shrubs. Hubada, Huliba, Boneiro and many other trees are common. Similar to Lo1 and often coincides with it where rooi forms the border of the limestone plateau (Rooi Barbacoa), and shares characteristic tree species, including Pal'i siya blanco and Wayaca. Large variety of uncommon to rare species such as Cawara blanco, Curahout, Huñagato, Mahawa, Giron and Wayaca shimaron, many of which found nowhere else.

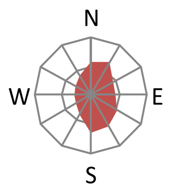
Ecology: Generally shallow topography with gentle side slopes (and therefore more windy) alternated by cliff edges (where more sheltered). Generally deep soils, sandy loam or loamy sand, often strongly water repellent and influenced by influx of goat droppings.

Additional ecological value: 72% of the plant species recorded during the field work were found in limestone rooien. Many rare species, including four only found in Rooi Mahawa which probably only have a handful of individuals on the whole island. Large variety of birds e.g. hummingbirds, flycatchers, warblers.

Disturbances: Average goat impact, though locally they gather in numbers for shelter as in Lo1, threatening the survival of rare species.







	Grass	Ground	Shrub	Canopy	Emergents
Height (m)		0.3	1.3	3.5	7.2
Cover (%)		3	27	69	

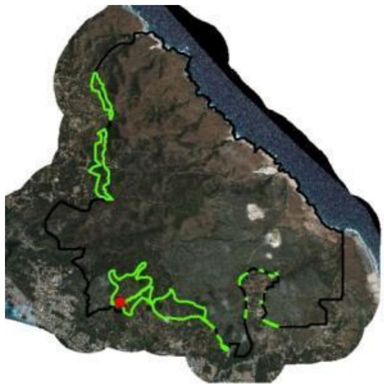
Species	Cover				
Aloe	s	Bringamosa	1	Dabaruida	2
Basora blanco	s	Bushi	s	Druif*	s
Basora preto	2	Cadushi	1	Flor di sanger	2
Beishi barranca	2	Calbas*	1	Fofoti*	s
Betonica	1	Camari	1	Giron*†	s
Boneiro	2	Cawara blanco*†	1	Grass	s
Brazil*†	1	Cordon di SF	s	Hubada	2
Breba	s	Cuco di Indjan	s	Huliba	2
Breba di pushi*	s	Cuihi	1	Huñagato*†	s
		Curahout*†	s	Kibrahacha*	s

Kiviti*†	1	Oleifi*	s	Taya	s
Loki-loki	2	Palo di lechi†	2	Tuna	2
Mahawa*†	s	Pal'i siya blanco†	1	Walishali	1
Mata combles*†	1	Pal'i siya cora*†	s	Watapana	1
Mata pisca	1	Palo cayente	1	Wayaca	1
Mata di yuana	2	Seida	1	Wayaca shimaron*†	s
Noni	1	Shimarucu	1		

Lo2 Rooi Thomas, dominated by Boneiro and Hubada with a Huliba bottom-left, several Wayaca top right and a Palo di lechi top left.

Lo2 Rooi Barbacoa with Basora preto and Seida in foreground and, various trees including Palo di lechi in background

4.4.4 Tonalite vegetation types



Tonalite disturbed (Th1)

Example location: 12°28’01”N -69°56’44”W (obs 89). When entering the park from Savaneta (entrance behind Isla) walk down into Rooi Awa Marga and up through the bush for about 100m.

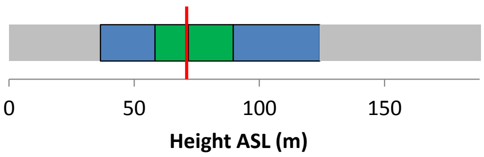
Occurrence: Southwest corner of the park near the park borders and the western edge of the park north and south of the visitor center. Area 2.0 km^2.

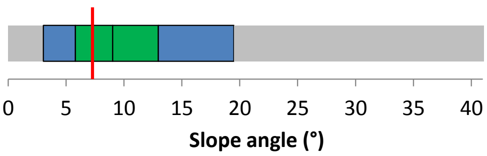
Recognition: Low Hubada-dominated woodland which is usually quite open, with a few other trees like Huliba, Watapana and Dabaruida and the common shrubs. Found in areas formerly under (Aloe) cultivation, and Aloe patches are characteristic.

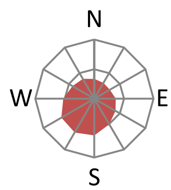
Ecology: Vegetation of tonalite area. Rolling hilly landscape with (loamy) sandy soils which are generally quite deep. High proportion of bare soil at the surface with some rocks and boulders. Common signs of erosion at the surface, especially in the more open, bare areas.

Additional ecological value: None

Disturbances: Goat presence high. Many remnants of stone walls (tranchi); a few large, possibly abandoned goat farms in the southwest corner. Previous cultivation (possibly aloe and other crops) has left a disturbed landscape with few tall trees and many open, bare spots.





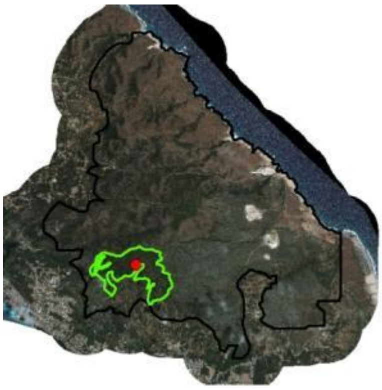


	Grass	Ground	Shrub	Canopy	Emergents
Height (m)		0.3	1	2.2	5
Cover (%)	<5	10	22	47	

Species	**Cover**				
Aloe	1	Cuihi	1	Shimarucu	1
Basora preto	2	Dabaruida	1	Taya	1
Boneiro	1	Grass	2	Tuna	1
Bushi	1	Hubada	3	Walishali	2
Cadushi	1	Huliba	1	Watapana	2
Cordon di SF	1	Cadushi di colebra	1		
		Loki-loki	1		


Th1 Low, open Hubada woodland with Cadushi and Aloe in the southwest tonalite area

Tonalite undisturbed (Th2)



Example location: 12°28’34”N -69°56’28”W (obs 87). Follow the track west from the Barbacoa dam for about 2 km and turn left at the first side trail. Example location is on the right after 50 m.

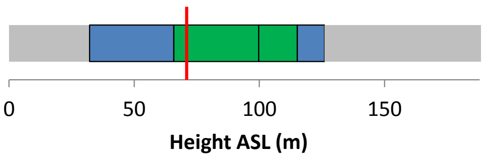
Occurrence: Southwest corner of the park, the part of the tonalite area bordering the diabase and limestone areas but away from the park borders. Area 1.5 km^2.

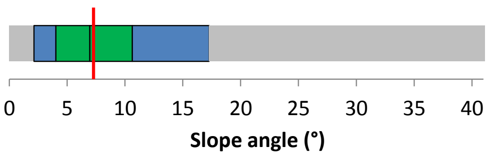
Recognition: Structurally more developed vegetation than Th1 with taller woodland and more species. Comparable to Dl2 and Dl3. Hubada dominant together with Dabaruida, Watapana and Mata di yuana. Large, old Pal’i siya blanco trees are characteristic for this vegetation type and Macubari can also be found. Clusters of Cuco di Indjan (agave) plants here and there.

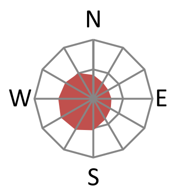
Ecology: Vegetation of the central tonalite area, higher hills than Th1. Deep, loamy sandy soils, with high proportion of bare soil and litter and few rocks at surface. Some erosion signs but less than in Th1.

Additional ecological value: Large variety of plant species, although the tonalite rooien are even more diverse.

Disturbances: Low to average goat presence, but wild donkeys roam free here and into the neighboring diabase area (Gran Tonel).







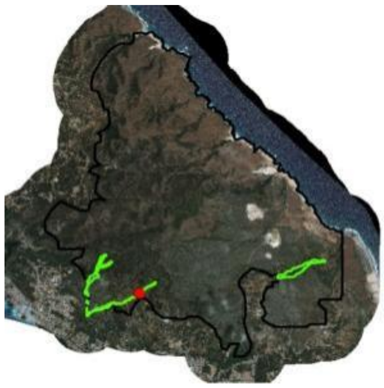
	Grass	Ground	Shrub	Canopy	Emergents
Height (m)		0.6	1.4	4.1	6.8
Cover (%)		20	43	75	

Species	**Cover**
Basora blanco	1
Basora preto	2
Betonica	1
Boneiro	1
Breba	s
Bringamosa	s
Bushi	1
Cadushi	2
Calbas*	s
Cuco di Indjan	s
Dabaruida	2
Flor di sanger	2
Grass	s
Hubada	2
Huliba	2
Huliba macho*†	s
Loki-loki	1
Macubari*†	1
Maripampun	s
Mata di yuana	2
Pal’i siya blanco†	1
Seida	1
Shimarucu	1
Taya	s
Tuna	2
Walishali	2
Watapana	2

Th2 Wayaca tree with Cadushi and Watapana in foreground. View over southwest tonalite area with Hubada woodland, looking northeast towards the limestone plateau

Th2 Large Pal'i siya blanco tree in the southwest tonalite area

Tonalite rooien (Tr1)



Example location: 12°28’08”N -69°56’27”W (obs 26). Enter the park from the southern Savaneta entrance past the Savaneta water tank. Walk down to the rooi and turn right into it, following it for about 500 m.

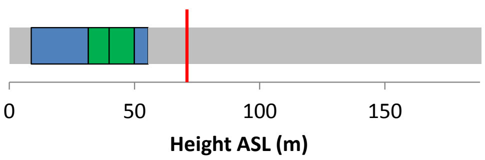
Occurrence: Rooi Lamunchi and Rooi Awa Marga in the southwest and Rooi Balaster in the southeast. Area 0.3 km^2.

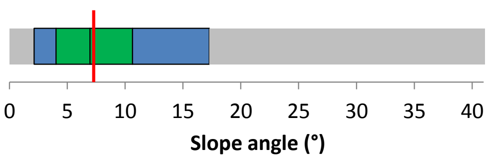
Recognition: Similar to Th2 but more diverse in species. Uncommon or rare plants found here include old Kiviti, Mosterd and Bushicuri (found nowhere else). Some parts overgrown with Cordon di SF.

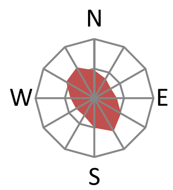
Ecology: Vegetation of tonalite rooien characterised by less steep side slopes than in the diabase rooien, and deep, sandy soils with some large rocks and boulders. Sometimes water repellent soils.

Additional ecological value: Some uncommon or rare plant species, many bird species and iguanas. In rooi Balaster 2 uncommon migratory songbird species observed (see annex 13).

Disturbances: Average goat presence in most places. Cordon di SF was found to overgrow vegetation in Rooi Lamunchi.







	Grass	Ground	Shrub	Canopy	Emergents
Height (m)		0.4	1.4	3.6	5.5
Cover (%)		6	20	97	

Species	**Cover**				
Basora blanco	1	Cucuisa	1	Mata di yuana	2
Basora preto	2	Cuihi	2	Pal’i siya blanco†	2
Betonica	1	Dabaruida	3	Pal’i siya cora*†	1
Boneiro	1	Flor di sanger	2	Seida	2
Bringamosa	1	Hubada	3	Shimarucu	2
Bushicuri*†	1	Huliba	1	Tuna	2
Cadushi	1	Kibrahacha*	1	Walishali	1
Calbas	1	Kiviti*†	1	Watapana	1
Cordon di SF	1	Loki-loki	1	Wayaca	1
		Maripampun	1		

Tr1 Dense Hubada woodland in upstream Rooi Lamunchi with Hubada. Watapana, Mata di yuana, Cadushi and Tuna

Tr1 Old Kiviti trees in Rooi Balaster

4.4.5 Unconsolidated vegetation types

Beaches (Uc1)

Example location: No observation points done in this vegetation type.

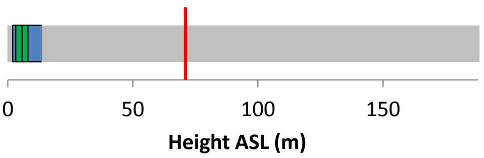
Occurrence: Boca Daimari, Boca Moro, Dos Playa and Boca Prins, with some smaller (rocky) beaches (e.g. Boca Bolongfa) not mapped. Area 0.06 km^2 (6 ha).

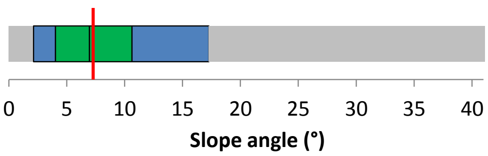
Recognition: Bare sand or rocks, with only a few scattered succulents (Banana di Rif) and salt-tolerant grasses. Sometimes a depression behind the beach ridge floods with salt water and can become a swamp (saliña), e.g. at Boca Daimari. At Boca Prins, Dos Playa, Boca Moro and Daimari, the beaches grade into dunes, Uc2.

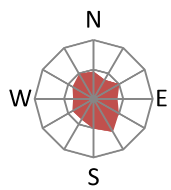
Ecology: Marine depositional sand, pebbles and/or rocks mixed with marine debris and trash.

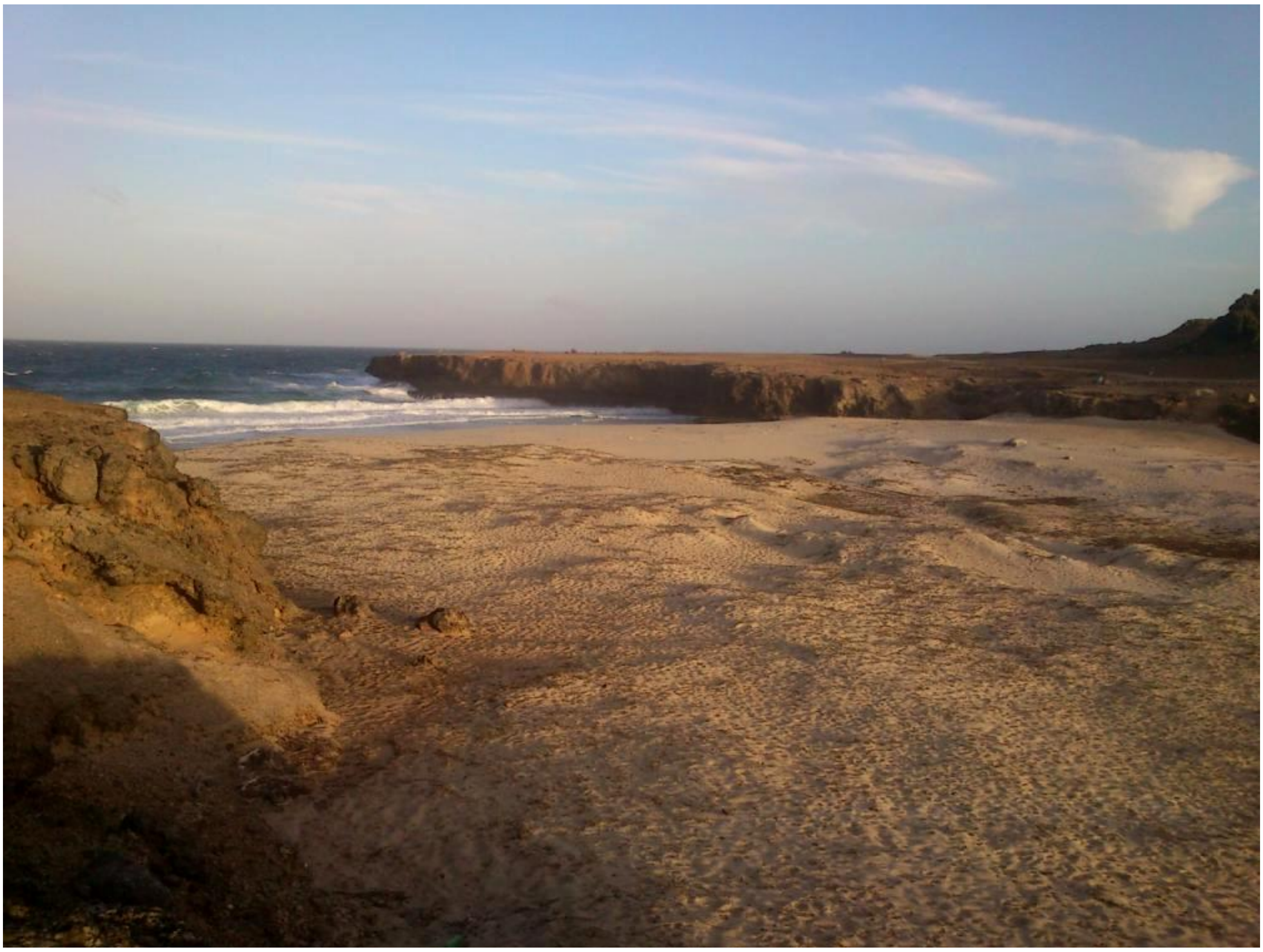
Additional ecological value: Valuable nesting sites for sea turtles. Feeding grounds for various migrant waders (sandpipers, plovers) and herons, especially the saliñas.

Disturbances: Off-road driving destroys the vegetation and threatens sea turtle nests, though much work has already been done to protect the beaches. Some beaches heavily polluted with trash washed ashore, especially the pebble beaches (e.g. Boca Bolongfa, Calcoriti).








Uc1 Dos Playa beach at sunset

Dunes (Uc2)

Example location: 12°29'54"N -69°54'37"W (obs 41). Turn left off the main park road just before Fontein onto the parking lot next to the dunes and walk 50m northeast into the dunes.

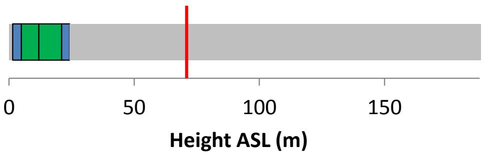
Occurrence: Boca Daimari, Boca Moro, Dos Playa and Boca Prins, just inland from the beach. Area 0.2 km^2 (17 ha).

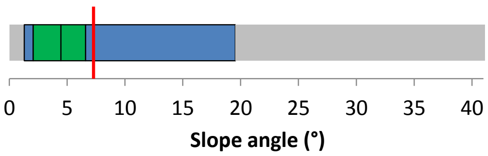
Recognition: Consists mostly of Druif forest, with low, creeping branches (windward sides of dunes) to tall trees (leeward sides), interspersed with bare sand. Few other species found, but they are specialized to the environment, e.g. Cocorobana. Manzaliña and Fofoti are found at the edges where this type grades into saline rooi mouths (Uc3).

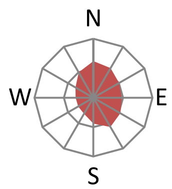
Ecology: Vegetation of low dunes which are longitudinal in direction of wind, ca. 5 m high. Deep, fine sandy soil originating from beach.

Additional ecological value: A unique vegetation type, habitat for crabs; fruits possibly eaten by birds and bats.

Disturbances: Goats presence low to very low; they do not seem to eat Druif leaves, only fruits. Off-road driving destroys root structure of trees and causes wind erosion. Drought seriously affected the trees during the study period.







	Grass	Ground	Shrub	Canopy	Emergents
Height (m)				3.5	
Cover (%)				93	

Species	**Cover**
Cocorobana	1
Druif	4
Fofoti	3

Uc2 Dunes with Druif forest at Dos Playa

Saline rooien (Uc3)

Example location: 12°30'17"N -69°55'12"W (obs 57). From the Dos Playa parking lot, walk down onto the beach and west into the rooi 100 m.

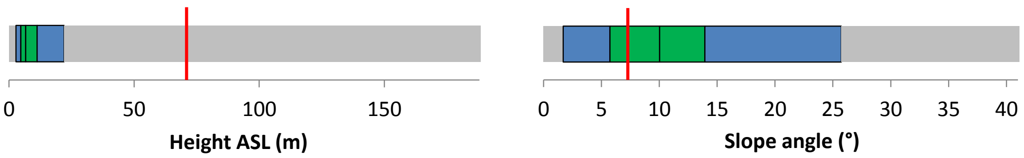
Occurrence: Rooi mouths of Rooi Prins and Tambu. Area 0.1 km2 (13 ha).

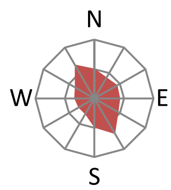
Recognition: Impenetrably dense, tall Fofoti forest, with Manzaliña and Druif trees along the edges. Manzaliña can reach 12m height at Dos Playa. Other species found along the edges which are typical for (saline) rooien include Cawara blanco, Oleifi, Mata di yuana and Yerba di sali.

Ecology: Vegetation of rooi mouths which occasionally flood with saltwater from the sea and freshwater runoff from the rooi. Deep, sandy to sandy loamy soils.

Additional ecological value: Like Uc2, a unique vegetation type. Many birds observed including migrant warblers, and valuable habitat for land crabs and hermit crabs.

Disturbances: Goat presence low; they do not seem to eat Fofoti or Manzaliña. Drought probably does affect these trees.





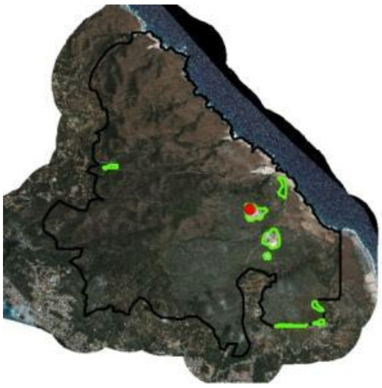
	Grass	Ground	Shrub	Canopy	Emergents
Height (m)		0.7	1.5	6.2	
Cover (%)		3	7	98	

Species	**Cover**
Basora preto	1
Cawari blanco	1
Druif	1
Fofoti	3
Hubada	1
Huliba	1
Manzaliña	2
Mata di yuana	1
Oleifi	2
Seida	1
Yerba di Sali	1

Uc3 Looking over dense Fofoti forest with Manzaliña in the background at the mouth of Rooi Tambu, Dos Playa

Uc3 Manzaliña forest at the mouth of Rooi Prins, near Boca Prins

4.4.6 Anthropogenic (A)



Example location: 12°29’20”N -69°54’49”W (obs 61). Quarry along concrete-track road from Jamanota to the plantation at Boca Prins (only observation point in this vegetation type).

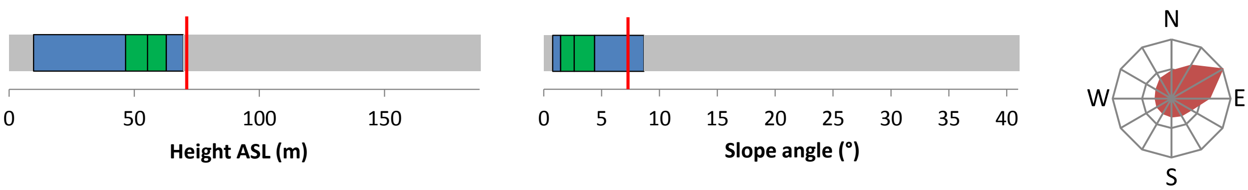
Occurrence: The plantation at Boca Prins, the limestone quarries, the visitors center area and a trash dump in the far southeast. Area 0.5 km2.

Recognition: Quarries are mostly bare with a few trees and shrubs starting to be established. The vegetation inventory is based on one observation point in a quarry. The Plantation at Boca Prins has a lush variety of native and exotic trees, especially dense around the freshwater source. The visitor center area is newly constructed and quite bare, except for the ‘Hofie Shon Shoco’ garden which is kept by the park rangers.

Ecology: Quarry has sandy soils, fairly deep in spots but with a lot of bare rock exposure. No erosion. Plantation Prins has the only natural year-round source of fresh water on the island. The trash dump has a thick layer (2 m plus) of accumulated rubble and trash.

Additional ecological value: Quarries have none, though tonalite excavations in other parts of the island attract nesting Shocos (Athene culicularia arubensis). Plantation at Boca Prins is a habitat for Cascabel (Crotalis unicolor) and has many birds, including migrant waders, attracted to the water and foliage. The visitor center area is the territory for one or two pairs of Shoco, which seem to nest in the road talus and like to perch on electricity wires. The Hofie Shon Shoco has many birds including orioles, hummingbirds and flycatchers.

Disturbances: Limestone quarries now abandoned but it will probably take many years before they return to a pre-disturbed state. Many visitors and cars at the plantation and the visitor center. The dump in the southeast is heavily polluted.



	Grass	Ground	Shrub	Canopy	Emergents
Height (m)		0.1	0.75	1.8	
Cover (%)	<5	1	25	40	

Species	Cover
Basora preto	2
Grass	1
Hubada	3
Seida	1

A Abandoned quarry near Drumidera with Beishi barranca (green) and Basora preto shrubs

5 Interpretation

In this section, the landscape-vegetation types are analyzed in light of information from experts and ranked according to their natural value. The vegetation of Arikok is then compared with vegetation of the neighboring islands Curaçao and Bonaire. Next, the opportunities and threats for future changes of the landscape-vegetation types are considered along with the drivers of these changes. Further details are given in annex 1, where a more detailed comparison is made with previous research.

5.1 Most and least desirable vegetation types

Most rangers and local experts consider the best vegetation to be diverse in species and to contain rare plant species. According to Carmabi biologist John de Freitas, the best vegetation is that which is better developed, with a taller tree layer and a developed shrub layer (13-10-2015, pers. comm.). Though most rangers in Aruba consider monotonous Hubada vegetation to be the worst vegetation type and even label Hubada an invasive species, De Freitas considers it to be a pioneer vegetation which will develop into better vegetation in time, supported by a study in Mexico (Reyes-Reyes *et al.*, 2002).

Following De Freitas, the most desirable vegetation can be described as: (1) the tallest vegetation, (2) that with the most rare tree species per plot (those marked with * in the descriptions) and (3) that with the most species per plot. Most herbs, grasses and succulents could not be identified in the field so they were not considered. The landscape-vegetation types were ranked according to their averages of these three criteria (table 1). Although Lo2 had by far the highest number of rare species (17, including 4 found nowhere else), the number of observations in this unit was also high resulting in a lower average number of rare species. Similarly, Dl3 had lower species total than Dr2 and Dl2, but a higher average number of species per plot resulting in a higher ranking.

Table 1 Ranking of the landscape-vegetation types. The numbers in brackets give the separate rankings for the three criteria (height, rare species and total species)

Rank	Diabase	Limestone	Tonalite	Unconsolidated
1			Tr1 (7,2,1)	
2	Dl3 (2,5,5)			
3	Dr2 (3,3,8)			
4		Lo2 (8,4,6)	Th2 (5,9,3)	
6		Lp2 (13,5,4)		Uc3 (1,1,20)
8	Dl2 (6,8,11)			
9		Lo1 (4,17,7)		
10		Lp4 (13,17,1)		
11	Dr1 (12,13,12)			
12	Dw4 (19,11,9)	Lp3 (17,14,9)		Uc2 (9,7,23)
15	Dw3 (11,16,15)			
16		Lt3 (9,17,19), Lp1 (22,10,14)	Th1 (16,17,12)	
19	Dl1 (15,17,17)	Lm (18,14,17)		
21	Dw2 (19,17,16)			
22		Lt1 (23,11,22)		
23	Dw1(21,17,21)			

Some vegetation types had (roughly) equal scores and were placed on the same level in the table. Overall it can be said that the rooien and the taller, less disturbed types contain the most desirable vegetation in each geological formation. The worst vegetation is found on the mostly bare, eroded slopes in the off-road driving area and near the coast (Dw1). Dw2, Dl1 and Lm are also considered bad (very low diversity).

Though Lt1 has a low ranking, there are several species of grasses and succulents which only occur here (but were not considered in the 'rare tree species' criterion). The same is probably true for Uc1, but no observation points were done here. The values of the Uc2 and Uc3 vegetation types are also probably underestimated because they are generally species-poor, but represent a unique vegetation types and a very specific habitat for particular plants and animals such as land crabs.

It should be noted that no negative factors such as invasive species were considered in this evaluation. The invasive plant Cordon di SF (Cordon di San Francisco, Rubber vine in English) was found in many landscape-ecological types but especially in the large diabase rooien and in the southwest border area of the park. It forms a threat to native vegetation, especially in the rooien where it overgrows whole areas, outcompeting (in terms of light) all other plants and trees.

5.2 Comparisons with Curaçao and Bonaire

During a short trip to Curaçao and Bonaire, I visited the national parks on these islands to compare the vegetation with that of Arikok.

5.2.1 Christoffelpark, Curaçao

Christoffelpark on Curaçao provides an example of what the vegetation on Aruba might have looked like hundreds of years ago (figure 3). Goats have been virtually eradicated from the park since the 1980s. Good vegetation on the diabase hills consists of tall woodland (ca. 4-6 m, taller near rooien, lower on ridges) dominated by Brazil, with many large Shimarucu, Mata di yuana, three kinds of Pal'i siya and many other species, some of which are not known from Aruba. The understory is not always well defined, but many patches of bromeliads are found on the ground in moister areas (low areas, near rooien). The rooien are covered in tall Manzaliña forest. On the highest peaks (with a different rock type belonging to the Knip formation) a stunted forest grows, very rich in tree species and with many epiphytes, including huge *Tillandsia* bromeliads and orchids, and ground *Bromelias*. Although Aruba may not be able to support such a forest due to the lower maximum elevation and lower rainfall, *Tillandsia* epiphytes do still occur around Jamanota, and orchids and ground *Bromelias* used to occur (StimAruba Tijdschrift, 1997). Brazil also used to be a dominant species on Aruba and was felled in large quantities during colonial times (Alofs, 1997). As such, the Christoffelpark vegetation may very well offer a glimpse of what Arikok used to look like.

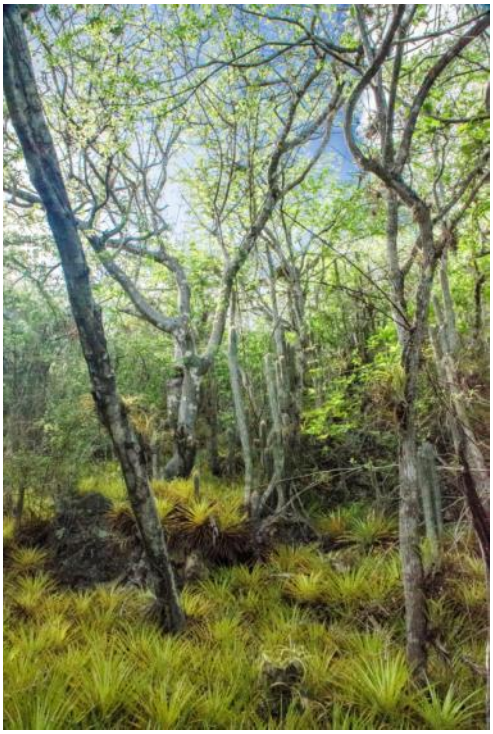


Figure 3 Tall woodland with a carpet of ground Bromelias in Christoffelpark.

Windward hillsides in Christoffelpark are covered in open woodland dominated by Camari. This is considered to be a climax type (Beers *et al.*, 1997) that should also possible for the Camari vegetation strips (Dw3) in Arikok which are now much more open, with more bare ground in between.

Vegetation of coastal terraces in Christoffelpark consists of open bushed woodland (3 m high) up to about 100m of the windward coast (figure 4). It is dominated by Brazil with quite a diversity of species, even on the lowest terrace. There are only 20 or 30 m of bare ground along the coast, compared with at least 500 m of bare land along the windward coast in Aruba. In neighboring Shete Boka park, where goats are allowed to roam free, the landscape looks a lot more like that of Arikok. As this difference is caused purely by the presence of goats, it would seem that Arikok could look very different if goats were excluded from the park.

Figure 4 Coastal vegetation in Christoffelpark.

The mature limestone vegetation, which should be the evergreen woodland as described by Stoffers (1956), was not clearly observed, as there are no higher limestone plateau areas in Christoffel park. However, judging from the description of limestone vegetation in Beers *et al.* (1997), this vegetation is also dominated by Brazil along with Camari, Mata Pisca and Palo di lechi. This supports the idea that the Lp2 vegetation in Arikok is indeed the least disturbed limestone vegetation most similar to the climax state.

5.2.2 Washington-Slagbaai Park, Bonaire

Washington-Slagbaai park in Bonaire is more similar to Arikok in terms of land use history (clear cutting of trees), number of goats still present in the park (many) and climate (almost as dry as Aruba). The park was established in 1969. Most vegetation in Washington-Slagbaai park consists of tall woodland (4-6 m), older and better-developed than in Arikok. Cuihi is dominant instead of Hubada, and local rangers frown upon this vegetation just like Hubada is disliked by Arikok rangers. However, both Cuihi and Hubada are pioneer trees which should eventually give way to more diverse vegetation (Reyes-Reyes *et al*., 2002). Around the main ridge with the highest peaks, there are areas with woodland dominated by Brazil and other tree species (figure 5), with many Pal'i siya blanco and cora, which again look more like the 'original' state.

Figure 5 Brazil-dominated woodland on taller hills of Washington-Slagbaai park.

Along the coast, the vegetation is very open, much like Arikok in some places but with a bit more vegetation cover. Moving from the foot of the hills towards the coast, Cuihi shrubland with many tall cacti becomes more open (bare areas interspersed with Cuihi 'mounds') continuing to within 100 m of the coast. This vegetation seems less good than Christoffelpark, but still much better developed than Arikok, which has 500 m of bare land next to the coast. It is not clear what causes this difference, though it could lie in slightly more favourable climatic conditions (more rain, less wind), the different topography (less steep hills with a broader foot plain), or the older age of the park.

5.2.3 Summary

The vegetation in Arikok is nowhere as good as in Christoffelpark, and for the most part worse than in Washington-Slagbaai. Nowhere in the park do we find tall woodland dominated by Brazil (which seems to be the original dominant plant species on both diabase and limestone) except maybe a few tiny, isolated, difficult-to-reach patches (e.g. the far south of the park, figure 6). We do find some areas with taller woodland, high diversity and rare tree species, especially in the lee of the hills and in the rooien. Many trees and plants are rare or have died out on the island. Some which are characteristic for a vegetation type (e.g. ground *Bromelias*) may have been common in the past in suitable spots, others may have been inherently uncommon.

Figure 6 Small patch of Brazil woodland in southern tip of Arikok Park; see figure 9 for the location

5.3 Opportunities and threats for changes in vegetation types

The comparisons with Curaçao and Bonaire show that Arikok's vegetation is a long call from the vegetation of Christoffelpark. The direction in which vegetation will change depends on management decisions, as well as changes in outside factors such as climate change. In this section, the possible changes for each vegetation type will be considered, along with the opportunities and threats which can drive these changes. Table 2 summarises some of the possible changes, the likelihood of these changes, the driving forces for each vegetation type and what can be done about it. More practical advice is given in the 'Recommendations' section.

5.3.1 Diabase group

For the diabase landscape-vegetation types, the most desirable units are Dl3 and Dr2. Whether Dl2 could transition to Dl3 is not certain; it would in any case require a diversification of species, maturing of the vegetation and for other species to take over dominance from Hubada. Dl1 could (and is expected to) transition to Dl2 as Hubada trees mature, giving chances for other species (such as Brazil and Kibrahacha) to be established, which would constitute a big improvement.

For the diabase rooien, the vegetation would ideally grow taller and become more diverse. This partly depends on the propagation of less common plants , which is probably limited by overgrazing, although soil properties and moisture are also important. Goat exclusion would be an important measure. Replanting efforts are also possible as long as they take soil and moisture conditions into account. Dr2 would present the best opportunities since these rooien are the most sheltered. Dr1 rooien are often more exposed, have shallower soils and receive less moisture. Cordon di SF overgrowth is a serious threat for rooi vegetation. It could be tackled using biological control measures (see the recommendations).

Although the windward vegetation types are ranked much lower than the leeward and rooi types, an increase in vegetation cover would be desirable for the sake of halting soil degradation. For example, Dw1 could change to Dw2 if the existing vegetation (Hubada) had the chance to spread and colonize areas which are now bare. Though this may not seem to be an improvement, Hubada has been shown to be a pioneering species which can provide a conducive environment for other species to become established (Reyes-Reyes *et al.*, 2002). Infiltration is improved and erosion is reduced under a canopy cover. However, improvement of Dw1 seems unlikely as many of the bare soils are highly degraded and the influence of goats is high. Also, the vegetation is disturbed by off-road driving. Dust entrained from passing vehicles coats the downwind vegetation (see figure 7), and erosion gullies originating from the compacted roads cause damage to the nearby hillsides (pers. obs.). Dw2 faces similar problems. The Dw3 landscape-vegetation type could improve if Camari strips expand and cover more of the currently bare ground. However, if the old vegetation strips die off without regeneration this would lead to impoverishment.

Replanting might be an option, though this would be much more challenging on the open, windy hillsides of Dw3 compared to the sheltered rooien. Another important measure to protect the windward slopes in general from further degradation would be to control the extent of off-road driving.

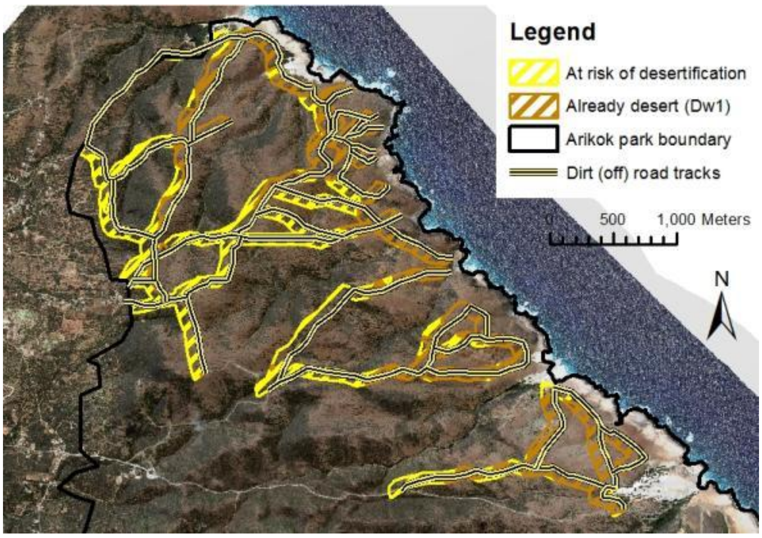


Figure 7 Theoretical risk map of dust from dirt road; the areas within 100m down-wind of dirt roads and tracks are shaded

As with the limestone area, the climax vegetation of the diabase group is thought to consist of a Brazil-dominated vegetation (Alofs, 1997; compare Beers *et al*., 1997 for Curaçao). Currently there are very few old Brazil trees remaining in the diabase landscape and equally few young plants. Most were found in the leeward hillsides. It will be a very slow process to restore the original Brazil vegetation to the diabase hills and it seems unlikely considering the current conditions (drought, overgrazing). Again, these problems would have to be overcome for any replanting efforts to succeed. See the recommendations for further details.

5.3.2 Limestone group

Within the limestone vegetation types, the most desirable vegetation is found in the rooien. Recovery here depends on the ability of rare trees to spread, which is limited by overgrazing. Possible solutions would be to (locally) eliminate goats through protective measures and to replant rare species. The next most desirable vegetation type is Lp2. There are opportunities for Lp1 and Lp3 to develop towards Lp2 with higher tree cover and more diversity. This would ideally be linked to the restoration of Brazil forests. This scenario could happen given the large number of young Brazil plants observed around the western edge of the limestone plateau, but would take many years because this tree grows very slowly. Again, goat exclusion would likely help, though the growth of these trees is also limited by climatic factors.

5.3.3 Tonalite group

Within the tonalite group, the rooien have the most desirable vegetation. The opportunities and threats here are similar to those of the diabase rooien. For the tonalite hills, the vegetation types are less strongly linked to landscape factors since there is not as much wind. It seems that the disturbed vegetation has the opportunity to develop into a less disturbed state if the influence of goats is kept to a minimum, but it will be a slow process on degraded soils.

5.3.4 Unconsolidated group

For the unconsolidated vegetation types, the best opportunity is maintaining their current extent and spreading onto nearby similar landscape areas where possible. For Uc3, the most desirable type in this group, it seems the Manzaliña forest could potentially extend land inwards into the large rooien as observed in Bonaire and Curaçao. It is not known whether Manzaliña forest was more extensive in the past on Aruba and if so, why it was reduced and what conditions are necessary for its restoration. Uc2, dune vegetation, could colonize more of the sand dunes if climatic conditions become more favourable and off-road driving is eliminated in those areas.

Table 2 Possible changes for a number of landscape-vegetation types, the likelihood of these changes given the current conditions and the main drivers of change.

Landscape vegetation code	Improvement	Likely?	Impoverishment	Likely?	Driving forces
Dw1	Increase in cover – to Dw2	no	Decrease in cover, soil degradation	yes	Overgrazing, drought, off-road driving
Dw2	Increase in cover, Brazil establishment	no	Reduction in vegetation cover, soil degradation – to Dw1	yes	Overgrazing, drought, off-road driving, dust from roads
Dw3	Increase in cover, spreading of vegetation strips, establishment of more species	no	Dying of old trees, erosion, dust deposition, reduction in vegetation cover – to Dw1	yes	Overgrazing, drought, dust from roads
Dl1	Increase in vegetation height – to Dl2 Brazil establishment	yes no	Decrease in cover – to Dw2	no	Overgrazing, drought
Dl2	Replacement of Hubada by other species, increase in diversity – possibly to Dl3	yes (slow)	Reduction in cover		Overgrazing
Dl3	Establishment of rare species		Takeover by Hubada		Overgrazing
Dr1	Increase in vegetation height – to Dr2	no	Dying off of old Fofoti trees	yes	Overgrazing, drought
Dr2 (also Lo2, Tr1)	(Re)establishment of rare species	mostly no	Dying off of rare species	mostly yes	Overgrazing, also drought (except Lo2)
Lt1			Lower ground cover	yes	Off-road driving, overgrazing
Lp1	More trees, Brazil- to Lp2	yes (slow)	Hubada takeover - to Lp3	no	Overgrazing
Lp2	Recovery of rare tree species Brazil grow back (slow)	yes locally	Dying off of old trees - to Lp1		Overgrazing
Lp3	Establishment of trees characteristic for evergreen woodland, Brazil – to Lp2	partly yes (slow)	Decrease of tree cover Hubada takeover		Overgrazing
Uc2	Spread of sea grape trees	no	Dying off of sea grape trees	yes	Drought
Uc3	Spreading of Manzaliña forest	no	Dying off of characteristic trees		Drought
A	Recovery of limestone vegetation in quarries	yes (slow)	Hubada takeover in quarries	yes	Overgrazing, drought

6 Recommendations and conclusion

6.1 Recommendations

Based on the opportunities and threats for vegetation restoration, conserving and restoring natural vegetation in Arikok Park could be done through a passive or active approach.

A passive approach involves mainly protecting the most desirable landscape-vegetation types (certain rooien, and the leeward sides of higher hills) from overgrazing. Alternatively, an effort could be made to exclude goats from larger areas, or eliminate them from the park altogether. It is difficult to find studies supporting such an approach in similar areas. Mekuria *et al.* (2007) showed that exclosures are effective measures in restoring vegetation cover, soil nutrients and productivity and reducing erosion in sub-humid Ethiopia (wetter than Aruba). A study in an arid shrubland in Israel (Leu *et al.*, 2014), which is dryer than Aruba, showed that reduced grazing pressure improved vegetation cover (patches of shrubs), soil nutrients, infiltration capacity and diversity of species. The conservation area here was under a strict grazing regime. Both these studies involved a balance of soil and vegetation restoration against usage of land for grazing, which is not the case in Arikok, where grazing is not officially a consideration. However, there are social implications to reducing the number of goats or eliminating them from the park.

There are various options to reduce overgrazing. Campbell and Donlan's (2005) review suggests several methods aimed at goat eradication from islands. Some may not be feasible in Aruba (aerial hunting, specialized hunting dogs), but the idea of using radio collared ('Judas') goats to track goat herds with the intent of removing them might be helpful in Arikok. In Christoffelpark, goats were mainly eliminated by hunting (Chris Schmitz, pers. comm., 19/10/2015), while in Washington-Slagbaai park, a program is underway using traditional goat traps, since shooting goats is deemed culturally inappropriate on Bonaire. All these options could be considered for Arikok. As long as the social debate about elimination of goats is ongoing on Aruba (E. ter Horst, pers. comm.) it would be preferable to at least exclude goats from a few smaller areas, where natural vegetation could start to recover. Besides protecting rare species from extinction, this could also provide illustrations of the effectiveness of the approach and convince a wider public of the importance of restoration. Suggestions for specific areas for prioritized protection are shown in figure 8, based on survey points with many rare species and personal observations. One opportunity is to use existing stone walls to section off goat exclusion areas in the southern limestone plateau (figure 9). Many of these walls are still in good shape and have a height of at least 1.5 m.

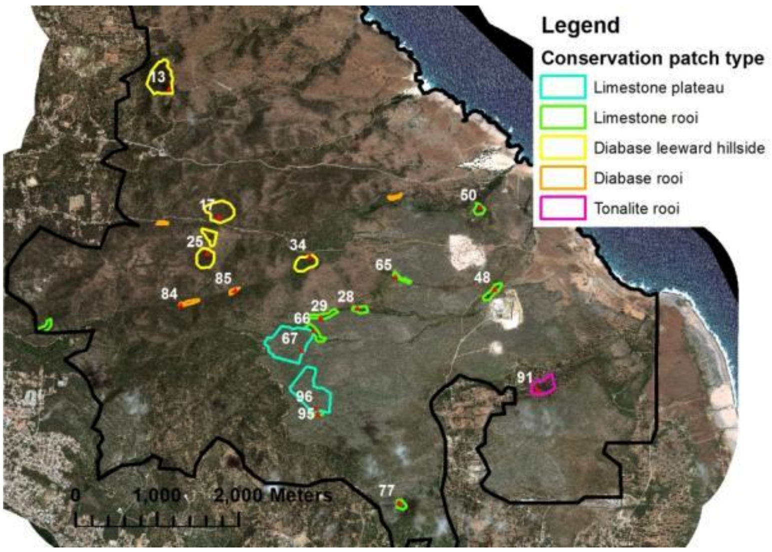


Figure 8 A suggestion of patches to be prioritized for passive and/ or active restoration. Coordinates of the numbered points can be found in the digital annex, file 'Observation points all data'.

In a review of ecological restoration literature, Ormerod (2003) concludes that the removal of the disturbing agent (passive approach) is often not sufficient to ensure restoration of an ecosystem to a pre-disturbance state. An active approach in Arikok would involve collecting seeds from plants of certain (rare) species and propagating them. It is common practice in dryland restoration to germinate seeds in a nursery and transplant seedlings to bypass the difficult germination stage (Minnick and Aldward, 2012). The best place for replanting depends on the specific soil and moisture requirements per species. A good place to start would be near existing individuals (because that is where the species naturally grows), in more mature woodland and in the rooien, where the conditions for establishment are more favourable (J. De Freitas, pers. comm., 20-10-2015). However, any replanting should only be done once a there is a good, proven plan for ensuring success of the replanted trees. Table 3 provides some suggestions for measures to aid seedling survival. StimAruba Tijdschrift (1997) provides some information specifically about multiplying native trees from seed. Additional information on the hydrology of Aruba's soils is given in annex 1.

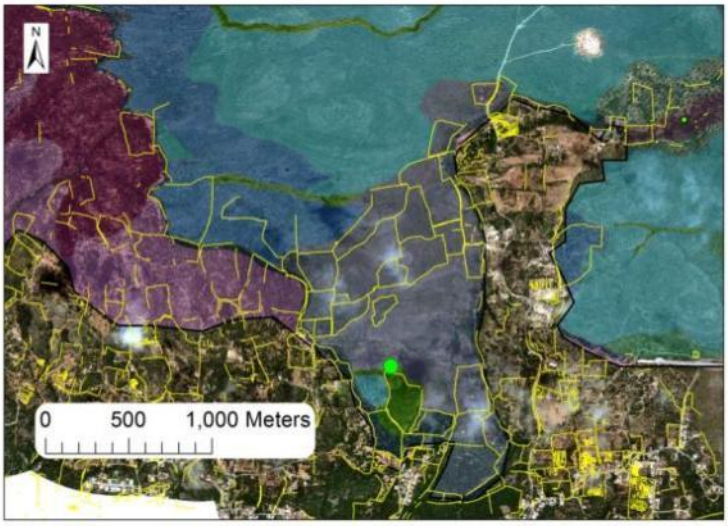


Figure 9 Location of stone walls in southern limestone plateau; green dot shows location of Brazil patch shown in figure 6 (observation point 77).

Table 3 Possible measures to increase replanting success.

Type of measure	Description	Reference
Soil structure	Soil preparation, deep plowing	Cortina *et al.* 2011
Water supply	(Drip) irrigation	Cortina *et al.* 2011
Water supply	Microcatchments	Cortina *et al.* 2011
Water retention	Hydro gel	Minnick and Alward 2012
Nutrients	Apply sewage sludge	Cortina *et al.* 2011
Reduce evaporation	Wood barrier next to seedling	Minnick and Alward 2012
Reduce evaporation and erosion	Piles of branches along contours (see annex 12)	Ludwig and Tongway 1996
Reduce evaporation, soil structure	Plant different species together or plant under canopy of other trees	Cortina *et al.* 2011
Patience	Repeat attempts over multiple seasons	Minnick and Alward 2012

In any case, it is advisable to have some further research and investigation done before replanting. focussing on the following questions: Which soil/moisture conditions are necessary for successful establishment of trees? Where are these soil conditions found? For example, in the limestone rooien, trees might well grow in the rooi beds, while in most diabase rooien, the seedlings in the rooi beds would get washed away during flash floods and should rather be planted along the rooi edges. Another important consideration is: what were the results of previous and ongoing replanting projects, on Aruba as well as on Curaçao and Bonaire? A previous replanting project on Aruba was not very successful, because goats ate the growing trees and possibly because the trees were killed by drought (see StimAruba Tijdschrift, 1997 and annex 11). Annex 5 gives a list of tree species being used in a reforestation project on Klein Bonaire. A good lesson about replanting is learned from Minnick and Alward (2012): in a semiarid environment with highly unpredictable rainfall, it is wise to plan for at least a few years of attempts to replant trees, since some of the attempts are likely to fail, even if all the necessary measures are taken.

An important measure to stop further degradation in the degraded northwestern diabase hills would be to control off-road driving. This would limit the amount of dust coating vegetation and slow down new gully formation. It seems unlikely that dirt-road and off-road tracks will ever be closed altogether as they form a huge attraction for tourists in jeeps, buggies and quad bikes. However, some of these tracks could be closed off, especially those leading away from the main Shete-Conchi road, using boulders, as is done in the southwest corner of the park on the road between Fontein and Vader Piet. This would have to be coupled with awareness-raising on the negative effects of off-road driving on the environment, especially among jeep drivers and 4WD tour guides. Such measures would not only benefit the diabase hills but also help preserve the coastal limestone vegetation and the beaches and dunes.

When it comes to combating the invasive vine Cordon di SF, there is something to learn from experience in Australia, where biological control has been successful at controlling this pest (Palmer *et al.*, 2010). A rust fungus from the vine's area of origin, Madagascar, specifically attacks only Cordon di SF, and has been shown to significantly reduce establishment and growth of the plant (Vogler and Lindsay, 2002). Introducing this fungus to Aruba may be a good option to control the invasion of this plant in the rooien of Arikok Park. However, introducing a pathogen to another continent is a project which should not be taken lightly. There are too many instances where introduction has led to unexpected effects. Analysing the local population of cordon di SF in terms of potentially harmful pests could be a preferable first course of action.

A final recommendation is to consider and stimulate societal involvement in vegetation restoration projects. Input and ideas from a range of local people can help to foresee and overcome practical problems, and it will result in support from the community. This could be done by implementing pilot projects, which would be evaluated through feedback sessions and other means, subsequently improved and transferred to a larger scale (Cortina *et al.*, 2011).

6.2 Conclusion

In conclusion, the most desirable landscape-vegetation types in Arikok Park are the rooien in all geological types, plus the well-developed types such as Dl3. These areas have the tallest vegetation with the largest number of rare species and most species total. Overall, the vegetation is much degraded compared to the vegetation of the national parks on Curaçao and Bonaire, which are to some extent illustrative of how Arikok's vegetation may have looked originally.

There are opportunities for development and improvement of vegetation, mainly through maturing of existing vegetation and establishment and spreading of rare species. The existing Hubada-dominated woodland on diabase grounds may well develop into more varied woodland in the course of natural succession, if overgrazing is reduced. However, the windward diabase vegetation is under threat of continued degradation, especially with the erosion and dust deposition resulting from off-road driving. Rare species are not likely to recover on their own, unless the influence of goats is removed. Replanting efforts could speed up the process and are most likely to be successful in places with well-developed vegetation with a more conducive environment for the establishment of seedlings. Recommendations include fencing off of small areas, replanting rare species (which would require extra research into methods and locations) and involving a range of people in planning larger projects to ensure success.

7 References

Several of the harder-to-find papers have been included in the digital annex (see annex 14).

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Annex 1 Academic annex

The primary goal of this research was to provide Arikok Park with practical knowledge in the form of the landscape-ecological map and descriptions, which can help them make improved management decisions leading to nature restoration. These results make up the main section of this report. However, another goal of this research was to investigate correlations between vegetation types and landscape factors in Arikok Park. This is necessary in order to know the extent to which physical factors affect the current state and (re)establishment of natural vegetation. Since it is more technical and may not be relevant for all of the audience of the main report, these analyses are separated into this academic annex.

First, the research questions are explained, followed by the conceptual framework underlying the methods. Next, the methods are explained in detail, including a justification of why these methods were chosen. In the 'Additional results and discussion' section, the results of the correlation analyses are explained and viewed in the light of previous research. The implications of these results for vegetation changes are discussed in 'Opportunities and threats'. Finally, the conclusion and further recommendations address the main question.

1 Research questions

<u>Main research question:</u>

Which areas of Arikok Park, Aruba offer potential for restoration and conservation of the *most desirable vegetation*, and which areas run a risk of changing to the least desirable vegetation?

<u>Sub questions:</u>

1. What are the actual vegetation (types) of the park?
2. What are the associated properties (site factors) of these types: i.e. what are their soil properties, geological and geomorphologic aspects (mother material, slope, aspect and exposure, hydrological situation), and external influence (off-road tracks, goat density)?
3. Where are the sites containing *"the most desirable vegetation"* and how can these be characterized in terms of species, vegetation structure and site factors?
4. Where are the sites containing *"the least desirable vegetation*" and how can these be characterized in terms of species, vegetation structure and site factors?
5. Which factors best predict the quality or non-quality of the vegetation?
6. Where are areas of threat (site factors closely associated with least desirable vegetation, but currently covered with desirable vegetation) and areas of opportunity (site factors closely associated with most desirable vegetation, but currently covered with least desirable vegetation)?

Sub questions 1 through 4 were mostly covered in the main text. Sub question 2 will be further elaborated here, especially the correlations between vegetation types and site factors. Sub questions 5 and 6 will also be looked at in more detail in this section.

2 Conceptual Framework

This research takes place within the framework of 'landscape-ecological mapping'. A landscape-ecological unit, also known as an 'ecotope', can be described as a "homogeneous eco-space of various landscape components, such as physiotope (topography, lithological features and soil), biotope (vegetation), and anthrotope (anthropogenic factors)" (Hong *et al.*, 2004). Such a map can be obtained by overlaying the individual component maps, such as geology, landscape, and vegetation maps and combining them (figure 1). In order to understand natural ecosystems, it is important to comprehend the relationship between the abiotic environment (such as landscape types) and biotic environment (such as vegetation structure) (Hong *et al.*, 2004).

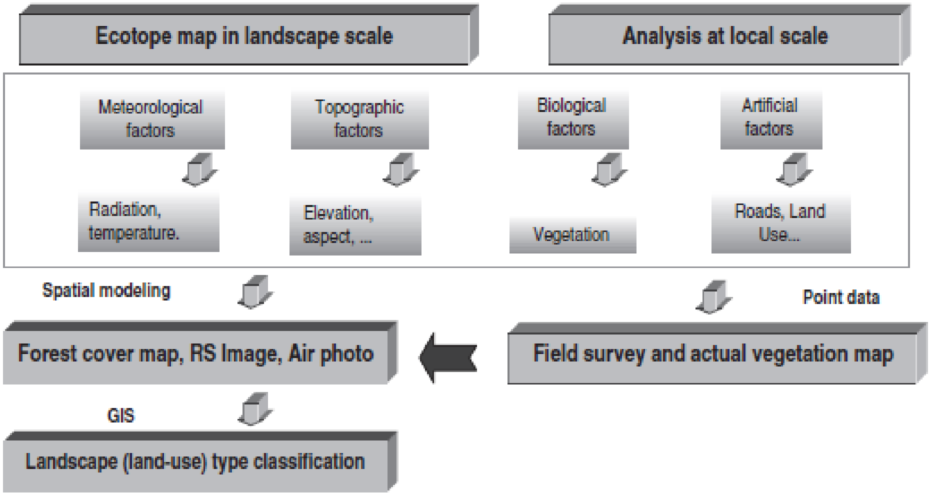


Figure 1 Adapted from Hong et al. (2004). Conceptual workflow for preparing an ecotope map. The landscape type classification in my research is the landscape-ecological map.

In this research, the relationships between abiotic and biotic environment are operationalized by establishing correlations between vegetation data and abiotic factors recorded in the field survey (point data), and by testing for differences in DEM-derived surface parameters such as slope and aspect between landscape-vegetation types (corresponding to 'spatial modelling' in figure 1).

The concepts of 'most desirable' and 'least desirable' vegetation have been chosen over a term such as 'natural vegetation' since there is very little knowledge on what the natural (original) vegetation was like on Aruba. Furthermore, it is questionable whether the 'natural state' is even a feasible target for nature conservation and restoration, and whether this state is adapted for future circumstances considering climate change (see Cortina *et al.*, 2011, Ormerod, 2003 and the discussion). In order to avoid (skirt) these issues, the term 'most desirable' vegetation is used since it could be arbitrarily filled in based on the knowledge of experts, the wishes of the park management and/or field observations of the current situation. It remains a subjective term since it is 'most desirable' primarily from the perspective of nature conservation, and not primarily from a perspective of recreational or economical functions.

3 Methods

The methods of research have been briefly described under the relevant sections in the main text. Here, the methods are explained and documented in more detail.

3.1 Preparation

The preparation consisted of collecting and studying relevant literature and digitizing maps. Much of the literature and maps of Aruba could only be found in physical form in Wageningen library. Other literature was found in the library at Arikok or through online searches.

The maps of geology (Rijksgeologische Dienst, 1996), landscape-soil (Grontmij and Sogreah, 1968) and vegetation (Stoffers, 1956) were scanned, georeferenced and digitized in ArcGIS (Esri Inc., 2014). I found an old but detailed contour line file at a government department in Aruba, which I cleaned up and converted to a DEM. This DEM was used to calculate slope and topographic wetness index (TWI) using the Geomorphometry and Gradient Metrics toolbox (Free Software Foundation, Inc., 1991). Finally, a wind strength map was calculated with the tool 'raster calculator' by combining an aspect map and a visibility map (made using the 'visibility' tool, a measure for 'openness' in the terrain). The aspect map had been rescaled from 0 to 1 (0 being for leeward, west facing slopes and 1 for windward, east facing slopes). All these maps are included in the digital annex (see annex 14).

3.2 Fieldwork

The fieldwork consisted of exploratory hikes with rangers to get to know the park and to select fieldwork locations. After this orientation phase, about 100 survey points were done, involving vegetation plots and recording of environmental factors.

Choosing fieldwork locations

Locations were chosen based on various criteria. First of all, the aim was to sample locations spread widely over the whole park and representing the full range of site factors being studied: geology (covering the main geological units), landscape units (covering most or all of the units on the landscape-soil map), and exposure to wind (windward to leeward). Different vegetation types were also to be included as far as they could be readily distinguished on the satellite image.

Based on the satellite image, I selected patches which showed 'typical' vegetation within a given area, and patches which seemed to hold 'special' or interesting vegetation (such as sheltered hillslopes or rooien). Once in the field, I conducted a few survey points in the middle of such 'typical' areas. Other points were chosen in interesting looking patches, either patches recognized from the satellite image or seen from the ground, for example where several interesting species were found in a generally monotonous area. Thus, the samples were not taken randomly: some plots were in 'typical' (average or representative for that area) patches and others in 'special' patches.

Vegetation plots

For the vegetation plots, I used the methods from the 'Vegetation' chapter in the Australian Soil and Land Survey Field Handbook (National Committee on Soil and Terrain, 2009, pp. 75-87) as a guideline, supplemented by information and ideas from Torello-Raventos *et al.* (2013). This method focuses on a classification based on structure (dividing vegetation into strata and recording their height and cover), which was also my goal, and it was found to be practical and easy to use.

The vegetation plots consisted of laying out a 5x5m plot using a string. Although 10x10m plots or larger are generally recommended for woodland, this was impossible to carry out within reasonable time in the impenetrable, thorny vegetation which characterizes Arikok. I moved through the plot to take a general look at the ground and the vegetation, then stood in the middle to record the specific parameters. First of all, I divided the vegetation in layers: dominant stratum, mid stratum and ground stratum. Any columnar cactus (Breba or Cadushi) sticking out a meter or more beyond the highest tree was generally considered an emergent. The tree layer, if present, was considered the dominant layer. The height of this layer was estimated as an average of the heights of the various trees. The middle layer was usually the shrub layer, but it could contain smaller individuals of the tree layer or tall individuals of species that are usually considered ground layer (Tuna). The lower plants were classified as ground stratum (usually < 0.5 m but sometimes up to 1 m). If there was any confusion about the number of layers, the preference was to choose fewer layers to prevent needless complexity. In some cases the dominant stratum consisted of shrubs (limestone plateau). In this case, scattered trees were classified as emergents.

I estimated the ground cover by imagining all litter, bare soil, rocks and bedrock separated out and moved to different corners of the plot, then estimating what percentage each would cover. The same is done for canopy cover, but by looking up. Canopy cover is defined as the total cover of all canopies over the plot, assuming the canopies to be opaque (having no holes). This eliminates the effect of seasons on crown cover, since most trees were bare during the research period. For percent cover of the middle and ground strata, the whole of the plant is again assumed opaque as if the plants had full crowns of leaves. To estimate height, the ‘measure height’ app on the smartphone was used, which uses the angle and the estimated distance from the base of the tree. Alternatively, an estimate was made using a multiple of my own height. All trees and shrubs were identified and as many of the smaller plants as possible, and for each identified species the cover was estimated using the Braun-Blanquet categories (see the table on the observation sheet, annex 6). Perennial herbs (which were mostly dry), lichens, mosses and bacterial and fungal films (similar to desert varnish) were not part of the survey.

At each vegetation plot, a number of other environmental factors were recorded like soil depth (estimated using a geological hammer digging tool), erosion, soil water repellence and goat influence. Conversion tables of these descriptive parameters to ordinal variables are shown in annex 7.

3.3 Data analysis

Stratification and mapping

After completing the field work, the survey points were grouped into categories which became the landscape-vegetation types, following the example of Beers *et al.* (1997). First, the observations points were grouped by geological unit. Within each geological type, the vegetation was grouped into intuitive landscape subdivisions. For diabase, this meant grouping the points into windward slopes, leeward slopes and rooien. For limestone, the divisions ran along the lines of lower and middle terrace and upper plateau (largely following the landscape-soil map, Grontmij and Sogreah, 1968). Within these subdivisions, the points were grouped by vegetation height and cover, resulting in some further subdivisions. After iterating this process several times, the final grouping was determined, which resulted in the legend for the landscape-ecological map. A short justification on why this stratification method was chosen is given in annex 8.

The whole of Arikok park was mapped into landscape-vegetation types by drawing polygons around similar-looking areas on the 2009 satellite image (source unknown; L. Boekhoudt, Aruba Department of Infrastructure and Planning [DIP], pers. comm., 10-2015). The locations of the survey points were used as representative ‘guides’ as to what that unit looks like on the satellite image. The landscape-soil, slope and aspect maps were used to help distinguish landscape types where necessary. For example, the aspect map was used to distinguish between windward and leeward slopes where the difference was not clear from the satellite image. The map was then tested and if necessary corrected on the basis of field visits using a printed preliminary version of the map. Polygons were checked and boundaries adjusted where necessary. All spatial analyses were done in ArcGIS (Esri Inc., 2014).

Evaluation of landscape-vegetation types

The resulting vegetation types were ranked on how ‘desirable’ they are based on three criteria recommended by De Freitas (pers. comm., 20-10-2015): vegetation height, average number of rare tree species (those species recorded in fewer than 10% of observations) per plot and total species number. Only rare tree species were included since no shrubs were found to be rare, and not all herbs could be identified. A fourth criterion recommended by De Freitas, vegetation structure, was not included because it was difficult to define a simple criterium that included the various strata and their cover. However, section 4.2 shows that there is a correlation between total species number on the one hand and mid-stratum height (r=0.40) and mid-stratum cover (r=0.38) on the other hand. Each landscape-vegetation type was ranked for each of the three criteria. These three ranks were averaged and the vegetation types were ranked again on these average ranks. These were the final ranks used to compare the vegetation types (table 1, main text).

Statistical tests

To check the basis and strength of the separation between mapping units, I investigated the landscape-vegetation types and their correlation (similarity)in terms of the plant species composition. To analyse relations between the abiotic and the biotic observations, I determined correlations between vegetation height, cover, species number and rare species on the one hand and soil depth, erosion situation, goat signs, and surface cover on the other hand, on a per survey point basis. These statistical tests were carried out in Microsoft Excel 2007.

I also tested for differences in surface parameters calculated in ArcGIS (height ASL, slope, TWI and wind strength) over the vegetation types. A normal T-test is not possible with spatial data, since the number of possible samples is infinite but they are not independent due to spatial autocorrelation. I used a bootstrapping method in which a large number of random points were produced within each landscape-vegetation type. The points had to have a minimum distance at which spatial autocorrelation was no longer an issue. The calculation to determine this distance was beyond the scope of this research, so the distance was set arbitrarily at 50m. This limited the number of random points per landscape-vegetation type to 50-400 per unit. The parameter values at these points were used as input for Tukey's HSD (pairwise) tests in Matlab R2015b (The Mathworks Inc., 2015). Using this method, the height, slope, TWI and wind strength of the landscape-vegetation types were compared pairwise among similar types (for example, the Dw units among each other).

4 Additional results and discussion

In this section, the results of these analyses are given to provide an idea of the support for the map units. First, the correlations between the landscape-vegetation types in terms of plant species composition are shown. Next, the various abiotic factors are correlated with vegetation in two steps: vegetation height, cover and (rare) species number are correlated with the environmental factors recorded at plot level, and the results of the spatial tests for differences in abiotic factors derived from the DEM are shown.

4.1 Vegetation types

Table 1 shows the correlations between the plant species composition of the landscape-vegetation types. It can be seen that most of the Diabase landscape-vegetation types show strong correlations among each other. The better-developed landscape-vegetation types (Dw3, Dl3 and Dr2) differ most from the other diabase types. Dw4 also stands apart because of the dominance of grasses, bearing a resemblance ($r=0.78$) to Lt1. The tonalite vegetation types are also very similar to the diabase, the better-developed vegetation (Th2) being the exception again.

Of the limestone landscape-vegetation types, most units are quite different from the other groups and from each other. The strongest resemblance is between Lp4 and Lp3 (both more disturbed limestone plateau areas) and Lp2 with both Lp1 and Lp3 (shrubland with Beishi barranca and/or Flor di Sanger). Lo1 and Lo2 also correlate well, which is to be expected since these units are often found side-by-side. Only Lt2 (and Lo2 somewhat) are similar to the diabase and tonalite groups, which could have to do with Lt2 being more disturbed by goats. The plant Beishi barranca is the only defining species found in Lt2 but not in the D and T units. Vegetation structure characteristics are not better at distinguishing between these units (these correlations are not shown, but included in the digital annex). The main difference therefore lies in the geology and resulting soil characteristics: limestone areas have mostly bedrock at the surface with pockets of soil, while the D and T groups all have a predominance of loose rock at the surface. This illustrates the difference between a landscape-ecological and a vegetation map: where Lt2 may have been grouped with

Table 1 Cross-correlation table of landscape-vegetation types by vegetation species. A high correlation means two units have similar species with similar cover. The colors are for visual support; blue is for high positive correlations and red for low positive to negative correlations.

	Dw1	*Dw2*	*Dw3*	*Dw4*	*Dl1*	*Dl2*	*Dl3*	*Dr1*	*Dr2*	*Lt1*	*Lt2*	*Lt3*	*Lp1*	*Lp2*	*Lp3*	*Lp4*	*Lo1*	*Lo2*	*Th1*	*Th2*	*Tr1*	*Uc2*	*Uc3*
Dw1	1.00																						
Dw2	0.83	1.00																					
Dw3	0.66	0.64	1.00																				
Dw4	0.73	0.71	0.41	1.00																			
Dl1	0.86	0.90	0.60	0.55	1.00																		
Dl2	0.86	0.86	0.59	0.57	0.88	1.00																	
Dl3	0.39	0.56	0.40	0.35	0.41	0.55	1.00																
Dr1	0.86	0.91	0.58	0.56	0.93	0.94	0.48	1.00															
Dr2	0.57	0.50	0.39	0.31	0.62	0.56	0.31	0.54	1.00														
Lt1	0.23	0.29	0.05	0.78	0.03	0.06	0.00	0.03	-0.02	1.00													
Lt2	0.79	0.78	0.62	0.51	0.75	0.70	0.48	0.72	0.38	0.06	1.00												
Lt3	0.14	0.04	0.14	0.01	0.00	0.02	-0.01	-0.01	0.34	0.00	0.01	1.00											
Lp1	0.05	0.17	0.18	0.02	0.05	0.02	0.23	0.03	-0.04	0.01	0.44	-0.02	1.00										
Lp2	-0.01	0.16	0.13	0.09	0.03	0.00	0.35	0.00	-0.01	0.00	0.33	0.21	0.59	1.00									
Lp3	0.21	0.29	0.28	0.17	0.17	0.26	0.57	0.13	0.31	0.00	0.40	0.42	0.34	0.61	1.00								
Lp4	0.34	0.27	0.18	0.36	0.21	0.42	0.32	0.21	0.39	0.29	0.21	0.01	0.07	-0.02	0.55	1.00							
Lo1	0.07	0.39	0.10	0.22	0.37	0.10	0.19	0.20	0.39	0.23	0.15	0.04	0.12	0.16	0.20	0.10	1.00						
Lo2	0.42	0.57	0.41	0.22	0.57	0.44	0.41	0.46	0.46	-0.03	0.54	0.28	0.39	0.42	0.47	0.23	0.52	1.00					
Th1	0.90	0.92	0.67	0.70	0.86	0.85	0.59	0.88	0.46	0.19	0.84	0.00	0.19	0.13	0.31	0.29	0.16	0.53	1.00				
Th2	0.31	0.51	0.25	0.22	0.43	0.56	0.57	0.51	0.39	-0.02	0.30	0.19	0.07	0.21	0.56	0.51	0.43	0.55	0.41	1.00			
Tr1	0.72	0.68	0.46	0.44	0.78	0.70	0.39	0.72	0.64	0.01	0.62	0.17	0.04	0.04	0.29	0.34	0.48	0.62	0.67	0.65	1.00		
Uc2	-0.04	-0.06	-0.06	-0.05	-0.04	-0.06	-0.08	-0.05	-0.04	0.00	-0.05	-0.04	-0.05	-0.08	-0.07	-0.05	-0.06	-0.02	-0.05	-0.08	-0.06	1.00	
Uc3	-0.03	-0.05	-0.06	-0.05	-0.03	-0.06	-0.09	-0.03	0.00	-0.03	-0.03	-0.05	-0.06	-0.10	-0.09	-0.06	-0.06	-0.02	-0.04	-0.10	-0.06	0.40	1.00

the D units in a vegetation map, the landscape-ecological approach makes a distinction based on geology and landscape (see also section 4.3 and 4.4 under 'Willemsen, 2011').

The unconsolidated landscape-vegetation types do not correlate with any other types, since they are quite unique, having mostly salt-tolerant vegetation species.

4.2 Abiotic factors - Plot level

Table 2 shows the correlations of abiotic factors, recorded at survey points, with factors characterizing vegetation structure (dominant and mid height and cover). The most important are positive correlations between structure and soil depth, water repellence and litter cover, and negative correlations with bedrock cover. The factors litter and water repellence are probably both an effect and a cause of higher vegetation cover. The leaves that fall from the woodland trees (Watapana especially, but also Hubada and Cuihi) seem to contain hydrophobic compounds, making the soil under them strongly water repellent during dry times (pers. obs. while doing the water repellence test, see annex 7). There have been no studies on the effects of water repellence on runoff and erosion in Aruba. In any case, a better-developed litter layer should lead to more soil organic matter and a more fertile soil, improving the conditions for other plants and trees. Soil depth is an important determining factor for soil water retention, and thus for establishment and development of vegetation. However, in places with less vegetation the soil is not held by roots, and raindrop impact on the soil is higher leading to more erosion. Soils are shallower in these areas and there is more rock exposure at the surface. Thus, soil depth, water repellence and litter cover all have an interaction effect with vegetation cover.

Table 2 Correlation table of the survey point data. The colors are for visual support: red is for large negative values, blue for large positive values, yellow for around zero. The framed boxes show larger correlations between vegetation parameters and abiotic factors.

	Erosion signs	*Soil depth*	*Water repellence*	*Texture*	*Litter*	*Soil*	*Rocks*	*Bedrock*	*Goats*	*Dominant Height*	*Dominant Cover*	*Mid1 Height*	*Mid1 Cover*	*Ground Height*	*Ground Cover*	*Grasses*	*Total number of species*	*Rare species*
Erosion signs	1.00																	
Soil depth	-0.24	1.00																
Water repellence	-0.08	-0.04	1.00															
Texture	0.08	-0.09	-0.07	1.00														
Litter	-0.01	0.36	0.14	-0.02	1.00													
Soil	0.00	0.28	-0.11	-0.09	-0.08	1.00												
Rocks	0.24	-0.41	-0.21	0.02	-0.49	-0.32	1.00											
Bedrock	-0.21	-0.09	0.15	0.07	-0.34	-0.26	-0.43	1.00										
Goats	-0.08	0.03	0.16	0.18	-0.11	-0.02	0.09	0.00	1.00									
Dominant Height	0.12	0.24	0.24	-0.12	0.53	0.12	-0.21	-0.34	-0.03	1.00								
Dominant Cover	0.11	0.31	0.10	-0.14	0.39	0.15	-0.22	-0.21	-0.12	0.47	1.00							
Mid1 Height	0.13	0.11	0.39	0.00	0.28	0.18	-0.11	-0.27	0.17	0.53	0.11	1.00						
Mid1 Cover	-0.08	0.05	0.13	0.07	0.06	0.02	-0.03	-0.09	0.05	0.18	-0.21	0.54	1.00					
Ground Height	0.26	-0.01	0.18	0.04	0.02	-0.11	0.11	-0.06	0.00	0.25	0.08	0.27	0.14	1.00				
Ground Cover	0.01	-0.13	-0.03	0.07	-0.01	-0.04	0.10	-0.06	-0.18	-0.07	-0.23	-0.03	-0.01	0.13	1.00			
Grasses	-0.03	-0.33	0.00	0.05	-0.24	0.02	0.14	0.06	-0.05	-0.26	-0.58	-0.03	-0.05	-0.10	0.47	1.00		
Total number of species	-0.12	0.02	0.31	0.14	0.14	0.05	-0.07	-0.07	0.05	0.16	0.03	0.40	0.38	0.19	0.13	0.06	1.00	
Rare species	-0.13	0.36	0.28	-0.02	0.30	0.07	-0.14	-0.16	-0.06	0.35	0.35	0.16	0.04	0.12	-0.11	-0.18	0.35	1.00

There are a few strong correlations between species parameters and other factors. Total number of species shows a positive correlation with middle stratum height and cover, while number of rare species shows a positive correlation with dominant height and cover. In other words, vegetation with a more complex structure has a higher diversity of species, while rare species are more often found in taller, closed woodland. Summarizing the above: taller, structurally developed woodlands with higher vegetation cover are often found on deep soils with a good litter layer, and have the most (rare) species.

Interestingly, the presence of goats does not seem to have much effect on vegetation structure and species, apart from a weak negative correlation (-0.18) with ground cover. However, it is hard to estimate goat presence simply by looking at amount of droppings, and it is likely that their effect is strong over the whole park. Erosion signs are also weakly correlated with vegetation. Soil depth probably has a more direct effect on vegetation than erosion signs.

4.3 Abiotic factors - Landscape level

In this section, the results of the analyses of surface parameters are shown. The analysis of the abiotic factors is used support the distinction made between mapping units, especially between similar types. The argumentation used here is different from that of an ecologist – who would argue that if there is a large similarity in vegetation composition there is no reason to have a different mapping unit. The full table of surface parameter values for all landscape-vegetation types is given in annex 9.

Of the limestone vegetation types, Lt1, Lo1 and Lo2 are quite distinct in terms of landscape (coastal terraces, escarpments and rooien respectively). Lp4 is found on a distinct geological unit and has significantly higher slopes than the other limestone plateau units. Lp1, Lp2 and Lp3 are found on the highest plateaus. The main differences between these units is their altitude (Lp2 is significantly higher) and their exposure to the wind, which is highest in Lp1 and lowest in Lp3 (table 3).

Table 3 Surface parameters of the upper limestone plateau landscape-vegetation types. Small letters (a, b, c) indicate results of pairwise tests: the same letter in the same column means two values did not differ significantly.

	Height (m)	Slope (°)	TWI	Wind strength
Lp1	78 a	3.4 a	7.7 a	48 a
Lp2	111 b	3.2 a	7.6 a	44 b
Lp3	79 a	2.8 a	8.2 a	37 b
Lp4	45 c	8.8 b	6.5 b	20 c

Among the diabase units, the windward diabase vegetation types, Dw1, 2, and 3 are found at increasing altitudes (table 4). Slope and wind strength are also determining factors for these three units: Dw1 has shallower slopes and Dw2 the steepest. Dw1 is the most under influence of the wind, Dw4 the least (but still more than the leeward vegetation types, see table 5).

Figure 2 shows that while Dw1 and 3 are found mostly on slopes directly facing the wind, Dw2 is largely found on S and SSE facing slopes. Dw4 is found both on windward and on leeward facing hillsides, and seems to be specifically connected with a specific rock type within the diabase formation (slate/schist). Although the aspect map was sometimes used in the mapping process, the satellite image and field checks were more important in delineating windward and leeward types and so the effect is largely independent of the analysis method.

Among the leeward diabase landscape-vegetation units, there are fewer distinguishing abiotic factors. Only Dl3 is found at significantly higher altitude, while the slope angle, TWI and wind strength are all roughly equal (table 5). From figure 3, it can be seen that the leeward vegetation types also do not differ much in their aspect. Only Dl1 is found more often on slopes at roughly right angles to the prevailing winds, receiving slightly more wind.

Table 4 Surface parameters of the windward diabase landscape-vegetation types. Small letters (a, b, c) indicate results of pairwise tests: the same letter in the same column means two values did not differ significantly.

	Height (m)	Slope (°)	TWI	Wind strength
Dw1	51 a	8.9 a	6.6 a	45 a
Dw2	80 b	14.4 b	6.2 b	35 b
Dw3	109 c	11.2 c	6.4 ab	36 b
Dw4	78 b	12.6 bc	6.1 ab	27 c

Table 5 Surface parameters of the leeward diabase landscape-vegetation types. Small letters (a, b, c) indicate results of pairwise tests: the same letter in the same column means two values did not differ significantly.

	Height (m)	Slope (°)	TWI	Wind strength
Dl1	82 a	14.0 a	6.3 a	23 a
Dl2	84 a	15.1 a	6.2 a	21 a
Dl3	100 b	14.8 a	6.1 a	21 a

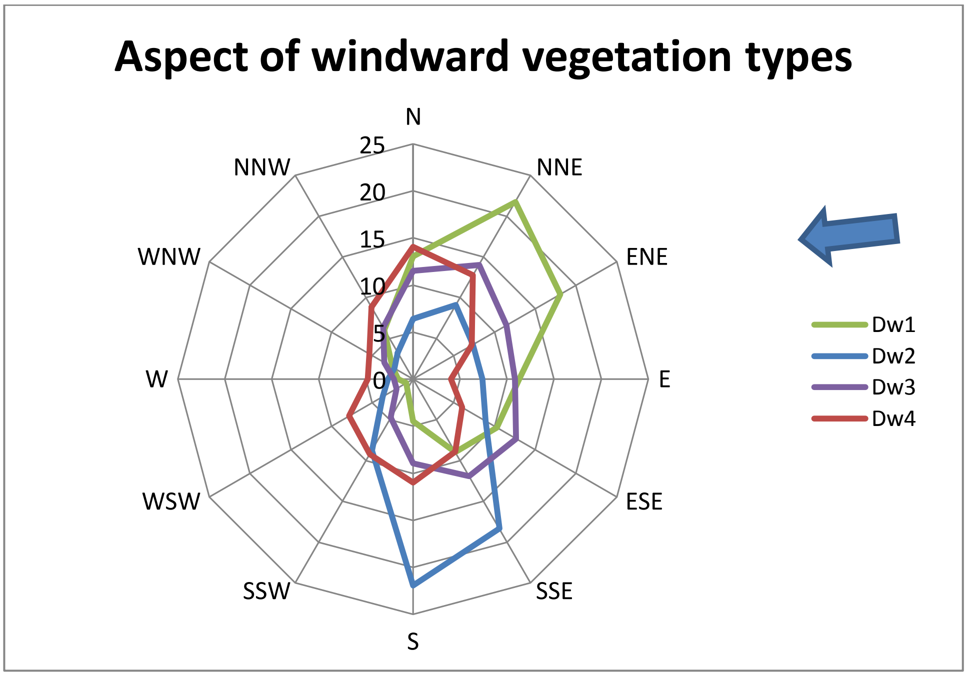


Figure 2 Aspect of the windward diabase landscape-vegetation types; the blue arrow shows direction of the prevailing trade winds.

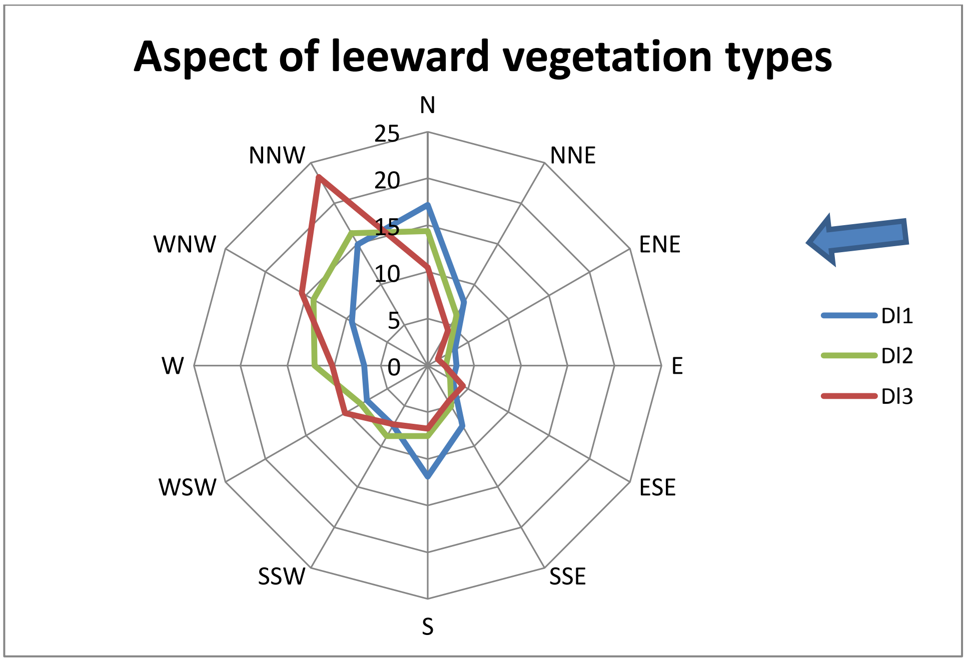


Figure 3 Aspect of the leeward diabase landscape-vegetation types; the blue arrow shows direction of the prevailing trade winds.

Dl1 and Dw2 are quite similar, both occurring mainly on slopes facing the wind sideways (N and S), both covered in low Hubada. They are similar in terms of altitude, slope and TWI (tables 4 and 5) and do not differ significantly on these counts (when tested with Tukey's HSD test); however, they do differ significantly in wind strength. They can be seen as transitional units between windward and leeward diabase landscape-vegetation types, with Dw2 more on the windward side of the transition and Dl1 more on the leeward side.

4.4 Comparison with previous vegetation surveys

In the main text, I already compared the vegetation of Arikok Park with that of Curaçao and Bonaire. Previous vegetation surveys have also been done in Arikok and in this section, I will attempt to compare my vegetation map with previous work and older images.

Stoffers, 1956

The standard work for vegetation of Aruba, Curaçao and Bonaire dates back to Stoffers' (1956) vegetation surveys and maps. Stoffers sampled locations all over Aruba, and came to the conclusion that no vegetation approaching 'natural' (original) vegetation could be found on the island. The original (climax) vegetation would have consisted of deciduous dry forest (on diabase and tonalite) and evergreen dry forest (found on limestone). The deciduous dry forest is characterized by a tree or shrub layer of 4-5 m, including some thorny and evergreen species, overtopped by scattered taller trees which are mostly deciduous. It is not completely clear from his study how he determined the characteristics of this vegetation or that this was Aruba's original vegetation. The deciduous dry forest can at least be found in near-original state on Curaçao as described in the main section, but original evergreen dry forest cannot be found even there (Stoffers, 1956 and Beers *et al.*, 1997). Stoffers describes various consecutive degradation forms derived from the climax forms (table 6).

Table 6 Stoffers' (1956) consecutive degradation vegetation communities

Limestone	**Diabase and tonalite**	
Evergreen dry forest (bushland)	Deciduous dry forest	Least disturbed
Evergreen dry woodland		
Thorny woodland derived from evergreen formations	Thorny woodland derived from deciduous formations	
	Cactus-thorn scrub	
	Cactus scrub	
Croton-Lantana-Cordia thicket derived from evergreen formations	Croton-Lantana-Cordia thicket derived from seasonal formations	
Vegetation of the rock pavement	Desert	Most disturbed

The thorny woodland and Croton-Lantana-Cordia thicket are the dominant types within Arikok Park on Stoffers' map (annex 10). However, his map is of the whole island of Aruba and is not very detailed. The thorny woodland derived from deciduous woodland covers most of the diabase landscape in Stoffers' map, which seems to indicate the vegetation was more varied as it includes species such as Brazil which are currently rare here. Other parts of the diabase landscape were mapped as 'Croton-Lantana-Cordia thicket' (Walishali, Flor di sanger and Basora preto) which are currently still very common as undergrowth in Hubada-dominated vegetation types, but are rarely found as a vegetation type of their own in the park. The 'cactus-thorn scrub', which accurately represents the current Hubada vegetation, was hardly found in Stoffers' map. Thus, it seems that the diabase vegetation has significantly changed since 1956, mostly degraded (if the assignment of most of the park to 'Thorny woodland' was indeed correct) and partly stayed the same, if not improved (the area which was 'Croton-Lantana-Cordia thicket'). The limestone area in the park is mapped as 'Thorny woodland derived from evergreen formations' by Stoffers. This can currently match up with only landscape-vegetation type Lp2 at best, since Lp1 lacks enough trees to be labelled 'woodland' and would fit more in the category 'Croton-Lantana-Cordia thicket derived from evergreen formations'. Thus, the limestone vegetation seems to have degraded since Stoffers' time.

Denters, 1979

Denters (1979a and b), researched vegetation structure in the area which is now Arikok Park in a recommendation report for the establishment of a national park. He interpreted air photos from 1949, 1957 and 1977 and recorded vegetation in plots, concluding that vegetation had degraded over the study period. Both the total vegetation cover and the proportion of tree cover had decreased. Since he did not define vegetation types, no direct comparison can be made with my research.

Roest, 1995

Roest's (1995) research (carried out within the "PUDRENA" project) focussed on mapping the vegetation types of the limestone plateau, at least the part which at that point was planned for inclusion in the future Arikok Park (later, a section of southern limestone plateau was added to the park). Roest surveyed vegetation at numerous points along transects and clustered the observation points automatically using Twinspan. The resulting 7 vegetation types were described in detail and mapped on paper, although the map is difficult to read. Broadly speaking, the vegetation types range from more disturbed to less disturbed. The more disturbed vegetation types usually consisted of shrubland without trees, with the weedy species Seida dominating (vegetation types 1, 2 and 4). He interpreted Seida as an indicator of recent disturbance since it is a pioneer species along with Tuna. These disturbed vegetation types were mainly found around the large quarries, in the eastern limestone plateau and around the agricultural area Butucu. This corresponds with vegetation type Lt2, Lt3 and (partly) Lp1 from my study.

The less disturbed limestone vegetation was found further west and south (vegetation types 5, 6 and 7). Type 6, the least disturbed vegetation type with the most trees, was found in the western part of the limestone plateau bordering the tonalite and diabase areas, corresponding with Lp2 in my study. Type 7 is characterized by epiphytes, which were not found anywhere in the limestone plateau in my fieldwork. The southern limestone plateau, roughly south of Rooi Mahawa (mapped largely as Lp3 in my research) was not surveyed by Roest but marked as 'abandoned agricultural lands of Kenepa and Asiboca'. This would explain the stone walls and many cacti (which were often used as property borders) found in this area.

Roest's research provides some interesting insights into the development and succession of vegetation on the limestone plateau. Also, Roest provides lists of species found in Rooi Barbacoa, Thomas and Mahawa, including many rare species which were not observed during my fieldwork. It seems that many of these species have only become rarer. These are added as a column in the adapted list from Van Belle *et al*. (2001) (annex 4).

Satellite image, 1998

The 1998 satellite image (source unknown, L. Boekhoudt, Aruba Department of Infrastructure and Planning [DIP], pers. comm., 10-2015), shows clear differences with the satellite image from 2009 and the 2015 drone photos (figure 4). The biggest differences are seen in the diabase areas: huge portions of land are seen as bare, or with only scattered trees, which in 2009 are covered in woodland (Hubada-dominated). It would seem that Hubada colonized large areas of the park in hardly more than 10 years. 1998 was a very dry time, while 2009 was particularly wet (informal information from park rangers, pers. comm.). Comparison with drone photos from 2015 (during another dry spell) shows that the Hubada overgrowth has persisted (greyish areas which were green on the 2009 photo and bare brown in 1998). This presents an interesting line of future research.

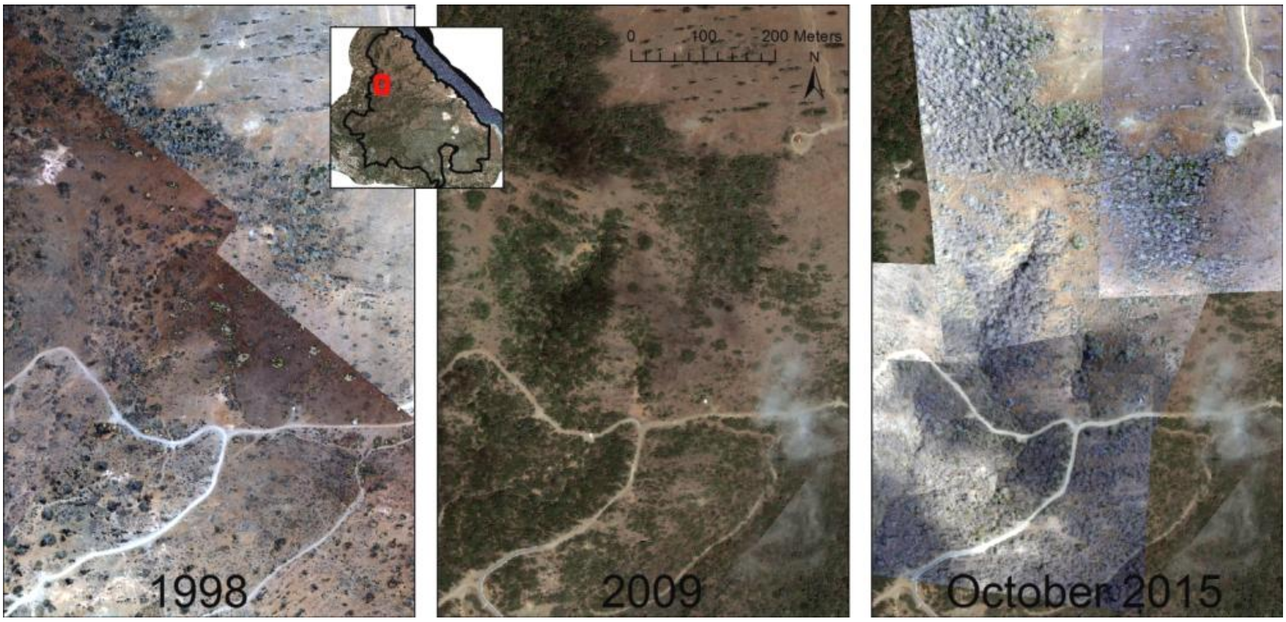


Figure 4 Comparison of 1998 air photo composite with 2009 satellite image and a composite of several images made with a drone during the field work in October 2015, of the area between the Arikok visitors center (not in view) and the summit of Arikok hill (top right corner). Notice especially the increased vegetation cover in center left and bottom left of the images.

Willemsen, 2011

Another student, M. Willemsen, did a similar vegetation mapping project in 2011. She did vegetation survey points at intervals along all the major roads and rooien and clustered them using Twinspan. The resulting vegetation map (annex 10) gives an impression of the vegetation types found in the park and especially the dominant and characteristic vegetation species. Her work was done during a particularly wet rainy season so she recorded many herbs which are not dealt with in my work. However, it is difficult to tell from the descriptions the general appearance or structural characteristics of a given vegetation type. Also, little information is given about environmental factors since this was not the focus of the report. Of the 7 vegetation types shown on the map, only 4 are described in detail; 3 others are said to be described in another report by R. Heirman, but this could not be found. Many areas on the map are left as 'unknown' since no survey points were carried out there (for example, the tonalite area).

Several vegetation types do correspond well with landscape-vegetation units from my research. Table 7 shows the seven types with the corresponding landscape-vegetation units. Willemsen followed an ecological (not landscape-ecological) approach, and so her map units are not based on geological or landscape divisions but on clustering of vegetation types. Vegetation type VII, for example, contains diabase, tonalite and limestone areas in windward and leeward hillsides, rooien and plateaus. As a result, the landscape-vegetation types which are closely correlated in terms of species composition (see table 1) tend to fall within the same vegetation type in Willemsen's research.

Table 7 Vegetation types from Willemsen (2011) and the corresponding landscape-vegetation types from the present research

	Vegetation type	Location	Corresponding types
I	Fofoti – Druif – Cocorobana	Coastal	Uc1, Uc2, Uc3, Lt1?
II	Camari – Basora Preto – Yerba chico	A few interior higher hills (mainly northern)	Dw3
III	Beishi di baranca – Seida – Funfun	Middle limestone plateau	Lt2
IV	Beishi di baranca – Walishali – Basora preto – Mata di piská	Upper limestone plateau	Lp1, Lp2, Lp3
V	Hubada – Mata di yuana – Cordon di SF	Major rooien, interior hills	Dr2, Lo2, Lo1, parts of Dl2, Dl3, Th1 and Th2
VI	Hubada – Breba – Camari	Northern, coastal and interior diabase hills	Dw1, Dw2, parts of Dl1 and Dl2
VII	Hubada – Walishali	Main part of central interior diabase hills, rooi Balaster area	Dl1, Dl2, Dl3, Lt3, parts of Dw2, Dr2, Lo1, Lt2 and Tr1

Conclusion

All in all, the comparisons with previous research help to see my research in a new perspective. Vegetation degradation was already going on most of the second half of the 20th century, and has certainly continued. Rare species have generally not recovered. Some vegetation types have seen a drastic increase in cover in the past decades through Hubada colonization, though the question remains how this will develop in the future. Other vegetation types, such as the Limestone vegetation, have remained virtually the same, or have seen slow degradation.

4.5 Towards a broader view of restoration targets

As mentioned in the conceptual framework, it is difficult to define the 'natural' vegetation in a place that has experienced severe degradation. Cortina *et al.* (2011) raise a similar issue for the case of southeast Spain. Southeast Spain has a semiarid climate similar to Aruba and has experienced widespread loss of vegetation cover and soil degradation. Cortina *et al.* (2011) suggest that restoration should focus not only on establishing a certain predefined community composition (a narrow restoration target), but also on recovering the overall functioning of an ecosystem and its ability to deliver services. The target should be a wider range of possible vegetation communities. Some examples of restoring ecosystem functioning include: improving soil conditions (counteracting degradation), restoring vegetation cover, and restoring important (keystone) species like trees. The implications for Arikok are that the focus should not only be on a single most desirable vegetation type, or on the spots currently containing the rarest species. There are wider opportunities for improvement of the vegetation of Arikok. For example, an increase in cover on the bare diabase slopes through restoring a Hubada cover can reduce erosion. Within the Hubada woodland, one or two keystone species may help to break the monotonous cover and provide space for other species to flourish. Another way to consider the ecosystem as a whole (Ormerod, 2003) would be by replanting key tree species which are important for insects, birds and bats. In Arikok Park, a varied ecosystem with birds like Prikichis (Aratinga pertinax arubensis) and Shocos (Athene culicularia arubensis) could have a tangible value as it could stimulate ecotourism, which is quite new for Aruba. Annex 13 contains more information on the birdlife of Arikok Park observed during field work.

4.6 Opportunities and threats

In the main section, the opportunities for improvement of vegetation within the limits of geology, landscape and climate were explained. These opportunities and threats can be further defined based on the links between landscape-vegetation types and abiotic factors and the comparison with the literature described above.

Among the three similar high limestone plateau units (Lp1, 2 and 3) there are only small differences in abiotic factors, mainly in altitude. The fact that the least disturbed vegetation is on the highest part of the plateau may only be a coincidence or may result from this area being more remote and less affected by humans, though there is no hard evidence for this. Since direct human disturbance is now no longer an issue, this means there is potential for restoration of landscape-vegetation types Lp1 and Lp3 into more desirable vegetation like Lp2.

Among the windward vegetation types, Dw3 is the most desirable but still not the ideal (climax) vegetation. Dw3 is found on higher slopes. This could be linked to less salt spray. G. van Buurt (pers. comm., 20-10-2015) indicated that salt spray can have an effect over the whole width of the island of Aruba. If salt spray is the main limiting factor for vegetation on the windward slopes near the sea, Dw3 patches on lower slopes are more at risk of degradation. On the other hand, patches of Dw1 and Dw2 located on higher ground experience better conditions for restoration. However, off-road driving counteracts this effect.

The only differentiating factor among the leeward diabase units is that Dl3 is found at higher altitudes. Like with Lp2, this might be a coincidence, or it might be a matter of less salt spray as with Dw3. It would be interesting to research the extent to which salt spray influences the entire width of the island, including the highest hills. Dl1 and Dl2 offer potential for restoration and development towards a more desirable vegetation. Dl1 could move towards Dl2, and Dl2 could move towards Dl3. This is especially likely in the patches of Dl1 and Dl2 which already contain more species and probably those that are most out of the reach of wind, further inland and behind the highest hills (Arikok, Jamanota and Gran Tonel).

5 Conclusion and recommendations for further research

5.1 Conclusion

In conclusion, the areas which have the best opportunities for vegetation restoration are those areas which already have better vegetation: places with a well-developed litter layer, deeper soils and a larger pool of species. Places with taller, denser canopy cover and a better vegetation structure are also more likely to have more (rare) species.

At a landscape level, altitude is the most important defining factor for the windward and leeward diabase landscape-vegetation types as well for the upper limestone plateau: the best vegetation exists at the highest altitudes, though the exact reasons are uncertain. In any case, this offers potential for the improvement of the other vegetation types which are found at similar landscape positions.

Comparison with previous research shows that there have been drastic changes in vegetation of Arikok Park over the past decades, and these changes are likely to continue. The fact that there are only a few significant differences in abiotic factors between desirable and less desirable landscape-vegetation types (between, for example Lp1 and Lp2 or Dl2 and Dl3) offers hope that these areas could develop into a more desirable vegetation. However, it should be considered that there are areas at risk: lower-lying areas of Dw2 and Dw3 are at risk of degrading to Dw1, especially where off-road driving induces water and wind erosion. Goat influence seems to be high everywhere. This problem especially needs to be dealt with before any active restoration efforts can be attempted, as explained in the main text. It is important to realize that restoration can have multiple outcomes, centering not on restoration of only one specific vegetation type but on improving different aspects of the vegetation leading to improved soils and more varied ecosystems.

5.2 Recommendations for further research

Further research could take several different angles. It would be interesting to do vegetation surveys with exclosure plots over a longer time period. Ideally, these would be combined with the recommended passive and/or active restoration steps (excluding goats from certain hotspots, replanting certain trees). So far, previous exclosure experiments have not succeeded for various reasons (see Roest, 1995).

Before any active restoration projects are undertaken, more research is needed on the suitability of tree species. Good sources of information include the StimAruba Tijdschrift (1997), local experts and organizations both on Aruba and on neighboring islands. Also, research would be needed on the soil and hydrological conditions to determine the best possible replanting sites, and whether any additional measures are needed to ensure seedling survival.

When it comes to restoring larger areas, especially in the degraded diabase hills, it would be important to know which areas are most affected by erosion, for example areas around off-road tracks. Such a study could be done through on-site erosion measurements with rainfall simulators, erosion plots or even sediment traps at the outlet of small catchments. Any approach using natural rainfall will be challenged with highly unpredictable rainfall. The effect of salt spray could also be researched to determine to what extent it affects vegetation across the park.

From another angle, it would be interesting to gain a better understanding of the ecology and succession of Hubada vegetation communities and the role of climatic variations on vegetation. For example, one could collect past rainfall data and compare them to NDVI maps or visually estimated vegetation cover from aerial images over a time period of several decades. This would help gain insight into past vegetation development, which could help understand future succession of Hubada woodland.

Annex 2 Hydrology of soils on Aruba

Due to the semi-arid climate and high evaporation rates, there is limited freshwater available on the island of Aruba (Grontmij and Sogreah, 1968). In the shallow soils, plant-available water is usually exhausted within 2-3 weeks after the last rains. The groundwater is generally around 5 m below ground level. The groundwater recharge rate is estimated at 5% of rainfall, or 20mm/year. There are few aquifers on the island. Some water can be found in weathered layers of both diabase and tonalite, in the tuff layers in the diabase, in fractures of the limestone, and in the loose sediments (alluvium) of the rooi valleys. The water in the tonalite feeds some wells which were used in the past to water livestock, yielding low amounts of around 1 L/s. The water quality of these wells is low with high EC and Na^+ concentrations due to salt water intrusion and salt spray from the sea (Van Sambeek *et al*., 2000). The lava formation rocks have practically zero permeability except for in fractures and tuff layers, and the soils are shallow. In the limestone, however, water infiltrates into cracks and fissures where it can be preserved as groundwater over a longer time. It is drawn up by deep-rooted plants and trees during the dry season, enabling more luxuriant evergreen vegetation in these areas than in the diabase landscape (Stoffers and Elassais, 1965). The limestone area also feeds the only natural well on the island at Fontein, which yields about 1L/s of fresh water(Grontmij and Sogreah, 1968).

Annex 3 Papiamento and scientific names of plants recorded during fieldwork.

The tree species recorded in <10% of observation points are marked with a * in the plant species tables in the vegetation descriptions (main text, section 4.4)

Papiamento name (Arnoldo*)	Scientific name (Arnoldo*)	Alt. Papiamento name (mainly from De Freitas**)	Alt. scientific name mainly from De Freitas**)	Trees recorded in <10% of observation points
Hubada	Acacia tortuosa			
Cadushi di colebra	Acanthocereus tetragonus	Cushicuri		
Cuco di indjan	Agave vivipara			
Cucuisa	Agave Karatto	Pita di trankera		
Aloe	Aloe vera			
Basora blanco	Bastardia viscosa			
Oleifi	Bontia daphnoides			x
Mata di yuana	Bourreria succulenta			
Pal'i siya (Pal’i siya) blanco	Bursera karsteniana	Palo di sia blanco	Bursera bonairensis	
Pal'i siya (Pal’i siya) cora	Bursera simaruba	Palo di sia cora		x
Pal'i siya (Pal’i siya) dushi	Bursera tomentosa	Palo di sia dushi		x
Watapana	Caesalpinia coriaria	Dividivi		
Catunbom	Calotropis procera			
(Palo di) Boneiro	Casearia tremula	Boneiro		
Breba	Cereus repandus		Subpilocereus repandus	
Bringamosa	Cnidoscolus urens			
Camari	Coccoloba swartzii			
Druif	Coccoloba uvifera			x
Mangel	Conocarpus erectus	Fofoti		x
Basora preto	Cordia curassavica			
Cawara blanko	Cordia dentata	Cawara (di mondi)		x
Zjiron	Crateva tapia	Giron		x
Calbas	Crescentia cujete	Calbas di mondi		x
Kiviti	Croton niveus	Kiviti		x
Walishali	Croton flavens			
Cordon di San Francisco (shortened to Cordon di SF in text)	Cryptostegia grandiflora			
Mosterd	Cynophalla flexuosa	Stoki	Capparis flexuosa	x
Kedebeshii	Cynophalla linearis	Quedebeshi	Capparis linearis	
Taya	Erithalis fruticosa	Mancha cashaca		

Palo di bonchi	Erythrina velutina			
Mahawa	Ficus brittonii			x
Wayaca	Guaiacum officinale	Wayaca		
Wayaca macho	Guaiacum sanctum	Wayaca shimaron		x
Macubari	Guapira pacurero	Labra		x
Brazil	Haematoxylum brasiletto			
Yerba di sali	Heliotropium ternatum?			
Manzaliña	Hippomane mancinella	Manzanilla		x
Mata pisca	Jacquinia arborea	Mata di pisca		
Seida	Jatropha gossypiifolia			
Flor di sanger	Lantana camara	Beishi		
Cocorobana	Mallotonia gnaphalodes			
Shimarucu	Malpighia emarginata			
Maripampun	Matelea rubra			
Bushi	Melocactus macracanthos			
Betonica	Melochia tomentosa	Basora cora		
Noni	Morinda citrifolia			
Bushicuri	Morisonia americana			x
Tuna	Opuntia caracassana			
Curahout	Peltophorum acutifolium			x
Loki-loki	Phyllanthus botryanthus			
Palo cayente	Pilocarpus goudatianus	Burachi		
Breba di pushi	Pilosocereus lanuginosus			x
Dabaruida	Pithecellobium unguis-cati	Pan cu queshi		
Cuihi	Prosopsis juliflora			
Huliba	Quadrella odoratissima	Huliba	Capparis odoratissima	
Huliba macho	Quadrella indica	Huliba macho	Capparis indica	x
Mata combles	Schoepfia schreberi			x
Banana di rif	Sesuvium portulacastrum			
Palo di lechi	Sideroxylon obovatum		Bumelia obovata	
Huñagato	Sphinga platyloba	Huñagato	Pithecellobium platylobum	x
Cadushi	Stenocereus griseus		Ritterocereus griseus	
Beishi di barranca	Stenostomum acutatum		Antirhea acutata	
Kibrahacha	Tabebuia billbergii			x

Barba di cadushi	Tillandsia recurvata	
Yerba di cabai	Tillandsia flexuosa	
Tarabara	Mimosa distachya	Huñagato, Huña huña
Grass	?	

*Arnoldo's zakflora, Proosdij *et al.*, 2001

**De inheemse bomen van de Benedenwindse eilanden, De Freitas, 1996

Annex 4 Rare plants of Aruba

The table from Van Belle *et al.* (2001) extended with records from Denters' map (1979b), Roest (1995) and my research. For further details see the relevant papers. The table is given in Dutch, as is the original table. In the 'Oosterhuis 2015' column, † marks rare species, <200 individuals according to Van Belle, marked with the same symbol in the landscape-vegetation descriptions (section 4.4). Further information on rare species can be found in the part C of the Environmental Assessment report (the sequel to Van Belle *et al.*'s paper) and the StimAruba Tijdschrift, both given in the digital annex (see annex 14).

Papiamento (Van Belle *et al.*, 2001)	**Latijns (Van Belle et al.)**	**Vindplaats (Van Belle et al.)**	**Situatie (Van Belle et al.)**	**Kaart Denters**	**Roest (1995)**	**Lokatie Roest (1995)**	**Oosterhuis 2015**	**Aantekeningen Oosterhuis (2015)**
(Bonchi largu)	Senna bicapsularis	diabaas	Geintroduceerd? Buiten park					
(Plaka chikitu)	Crossopetalum rhacoma	kalkterrassen	30 oude exemplaren		x	Rooi Thomas, Barbacoa		
(Yerba di yuana)	Celtis iguanaea	behalve harde kalksteen, alle grondsoorten	11 vitale exemplaren		x	Rooi Barbacoa		
(Yuka amara)	Manihot carthagensis		30 exemplaren op 1 plaats (ingevoerd?)					
Brazil	Haematoxylon brasiletto	verschillende	100-180 exemplaren	x	x		x†	Lijkt zich te herstellen, vooral op het kalkplateau veel jonge exemplaren in groot gebied rondom enkele oude bomen
Breba (Kadushi)	Subpilocereus repandus		algemeen				x	
Breba di pushi	Pilosocereus lanuginosus	alle grondsoorten	minst algemene van 3 zuilcactussen, 250-1000 exemplaren				x	
Cawara di mondi	Cordia dentata	behalve diabaas alle grondsoorten	100 exemplaren		x		x†	Verspreid over het park in vochtigere plekken, ook diabaas
Curahout	Peltophorum acutifolium		50-60 exemplare, matige vitaliteit	x	x	Rooi Thomas, Barbacoa	x†	Veel jonge exemplaren op sommige plaatsen in de rooien
Fofoti, Mangel	Laguncularia racemosa	kust	250-1000 exemplaren				x	
Giron	Cateva tapia	vochtigere plaatsen	16 wilde exemplaren matige vitaliteit				x†	
Huliba macho	Capparis indica	kalk	40-50 exemplaren		x	Rooi Thomas, Barbacoa	?†	Moeilijk te onderscheiden van Huliba
Kedebeshii	Capparis linearis	verschillende	>100 exemplaren, oud		x		x†	Veel zaailingen, maar lijken te lijden onder begrazing
Kiviti	Croton niveus	kalkheuvels	80-100 vitale exemplaren		x	Rooi Thomas, Barbacoa	x†	Komt redelijk veel voor, vooral rond de rand van het kalkplateau
Koushati	Krugiodendron ferreum	kalkheuvels	4 exemplaren		x	Rooi Mahawa		
Macubari	Guapira pacurero	alle grondsoorten	50-70 exemplaren	x	x	Rooi Thomas	x†	Verspreid over het park maar niet algemeen

Mahawa	Ficus brittonii	kalk	3 oude exemplaren op 1 groeiplaats	x	x	Rooi Mahawa	x†	Idem
Manzalina	Hippomane mancinella	strand					x	Boca Prins, Dos Playa en kleine zijtak
Manzalina macho (shimaron, bobo)	Metopium brownei	kalkterrassen	6 exemplaren in slechte conditie	x	x	Rooi Thomas		
Mata combles	Schoepfia schreberi	kalk	40 exemplaren matige vitaliteit		x	Rooi Thomas, Barbacoa	x†	Veel vitale exemplaren gevonden in verschillende rooien, ook Masiduri
Mosterd, Stoki	Capparis flexuosa	kalk	12 exemplaren, slechte staat	x			x†	Redelijk aantal exemplaren in kleine zij-takken van Barbacoa bij Gran Tonel
Pal'i siya blanco	Bursera bonairensis	alle grondsoorten	>100 exemplaren, beperkt voorkomend		x	Rooi Thomas, Barbacoa	x†	Redelijk veel gevonden verspreid over het hele park
Pal'i siya cora	Bursera simaruba		7 exemplaren	x			x†	*zie aantekening
Pal'i siya dushi	Bursera tomentosa	alle grondsoorten	~100 exemplaren, beperkt		x	Rooi Thomas	x†	**zie aantekening
Palo cayente	Pilocarpus goudotianus	kalkheuvels	1 groeiplaats, lokaal algemeen		x		x	Algemeen in grote delen van het kalkplateau
Palo di boonchi	Erythrina velutina		30-40 wilde exemplaren	x			x†	Twee rond Miralamar, vrij veel rond Rooi Mahawa in voormalig landbouwgebied
Palo di colebra	Maytenus tetragona	kalkterrassen	3 exemplaren op 1 groeiplaats		x	Rooi Mahawa		
Palo di lechi	Sideroxylon obovatum		80-100 matig vitale exemplaren op 20 groeiplaatsen		x	Rooi Thomas, Barbacoa	x†	Vooral op hoogste delen kalkplateau, langs rand en in rooien
Taki	Geoffroea spinosa		40 exemplaren matige vitaliteit					
Wayaca	Guaiacum officinale		1000-5000 over heel Aruba	x	x	Rooi Thomas, Barbacoa	x	Verspreid over het hele park, meest oude exemplaren
Wayaca shimaron	Guaiacum sanctum	kalkterrassen	18 niet-vitale exemplaren		x	Rooi Thomas	x†	2 in Rooi Mahawa, 1 langs rand van Isla gevonden
	Guapira fragans		bijna uitgestorven					

Overige soort niet door Belle genoemd, wel in het rapport van Roest (1995), gevonden in rooi Thomas, Barbacoa en/of Mahawa

Baishi blanco (?)	Rauvolfia viridis				x	Rooi Thomas		

Overige soorten niet door Belle genoemd, wel op de kaart van Denters

Calbas	Crescentia cujete	alle grondsoorten					x	Verspreid over het hele park
Kibrahacha	Tabebuia billbergii	kenmerk van seizoensgebonden loofverliezend bos					x	Verspreid voorkomend in diabaas gebied

Overige zeldzame soorten

Bushicuri	Morisonia americana						x†	Zeer zeldzaam volgens rangers; Rooi Awa Marga

*Jonge exemplaren moeilijk te onderscheiden van andere Bursera in droge tijd. Met zekerheid 5 grote exemplaren gezien langs rand van het park. 3 op kalk klif langs zijtak van Rooi Taki in prive-terrein vlakbij het Defensie schietterrein, 1 op de rand van het kalkplateau langs Rooi Lamunchi tegenover Isla net buiten het park, en 1 stervende in Rooi Awa Marga. Zeer waarschijnlijk ook in Rooi Prins.
**Moeilijk te onderscheiden van andere Bursera in droge tijd. Met zekerheid gezien in Rooi Mahawa, in het begin van Rooi Tambu rechts van de weg vlak na Miralamar vanaf het bezoekerscentrum gezien, en langs het voetpad omhoog naar Jamanota heuvel.

Annex 5 List of tree species used in reforestation on Klein Bonaire

Source: Lauren Schmaltz, Echo Bonaire, pers. comm., 11/18/2015.

Scientific name	Papiamento name and status on Aruba
Sabal cf. Causarium	Sabal palm – not found on Aruba
Guaiacum sanctum	Wayaca shimaron – very rare on Aruba
Cynophalla hastata	?
Bourreria succulenta	Mata di yuana – common on Aruba
Quadrella odoratissima	Huliba – common on Aruba
Crossopetulum rhacoma	Very rare on Aruba, no name (Palu di pushi on Bonaire, Plaka chikitu on Curaçao)
Melicoccus bijugatus	Kenepa (exotic?)
Sophora tomentosa	Pantropical leguminous weed
Celtis iguanaea	Very rare on Aruba, no name. (Beshi di yuana on Bonaire, Rambeshi, Yerba di yuana)
Erithalis fruticusm	?
Jacquinia arborea	Mata pisca – common on limestone plateau
Spondias mombin	Hoba/Oba (not found on Aruba, partly spread by humans)

Annex 6 Observation sheet

<table>
<tr><td colspan="5">Date</td><td colspan="3">Time</td></tr>
<tr><td colspan="8">Location and waypoint number</td></tr>
<tr><td colspan="8">General impression</td></tr>
<tr><td colspan="8">Geological unit (according to map)</td></tr>
<tr><td colspan="8">Rock types found on the ground</td></tr>
<tr><td colspan="8">Landscape unit (map)</td></tr>
<tr><td colspan="5">Position in landscape</td><td>Altitude</td><td>Slope angle</td><td>Aspect</td></tr>
<tr><td colspan="8">Erosion signs visible?</td></tr>
<tr><td colspan="8">Soil characteristics (depth, crust, water repellence)</td></tr>
<tr><td>surface cover in percent:</td><td>litter</td><td>soil</td><td colspan="2">rocks/gravel</td><td colspan="3">bedrock</td></tr>
<tr><td colspan="8">Texture of top 10 cm according to ‘feel test’</td></tr>
<tr><td colspan="8">Fauna seen</td></tr>
<tr><td colspan="8">Goat droppings, paths, damage from feeding?</td></tr>
<tr><td colspan="8">Other disturbances</td></tr>
</table>

Vegetation species and cover within 5x5m quadrant

<table>
<tr><td>Layer</td><td>height</td><td>cover</td><td>crown type</td><td>Dominant species and cover-abundance (Braun-Blanquet scale), or nearby species (ca 10 m around plot)</td></tr>
<tr><td>Emergents (<5% cover)</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">nearby species</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Dominant stratum</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">nearby species</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Mid-stratum</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Mid-stratum 2</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Ground stratum</td><td></td><td></td><td></td><td></td></tr>
<tr><td>nearby species in lower strata</td><td colspan="4"></td></tr>
</table>

Braun-Blanquet cover-abundance scale (simplified)

s	+	1	2	3	4	5
single plant, <5% cover	multiple, <5% cover	many, <5% cover	5-25% cover	25-50% cover	50-75% cover	<75% cover

Annex 7 Several rating tables for environmental factors recorded in the survey plots

Erosion signs (visually observed)

1	No erosion signs visible
2	Mild erosion signs visible: some accumulation of gravel on surface, or of organic material behind barriers.
3	Severe erosion signs: bare roots, gullying.
w	Wind erosion: rock pavement on surface
d	Deposition

Soil depth (measured in shallow pit dug with geological hammer)

1	Very shallow: <5 cm till (impenetrable) rocks
2	Shallow: 5-10 cm till (impenetrable) rocks, with possible small pockets of deeper soil
3	Moderately deep: >10 cm deep till rocks, at least in large pockets
4	Deep: >20 cm deep soil everywhere (past depth of digging tool)

Soil water repellence (measured with water put on handful of soil)

1	Not water repellent: water absorbs immediately into soil in hand
2	Slightly water repellent: water sits on soil and absorbs within 5s
3	Strongly water repellent: water sits on soil without absorbing for >10s

Goat disturbance (observations of goat droppings, paths and damage)

Value	**Designation in text**	**Field indicator (only for 1, 2 and 3)**
1	Very low	No sign of goats, neither droppings nor damage done
1.5	Low	
2	Average	Low disturbance: few droppings in plot and/or paths nearby
2.5	High	
3	Very high	Strong disturbance: many dropping and paths, trampled bushes and/or damaged tree bark

Texture

1	Sand
2	Loamy sand
3	Sandy loam
4	Loam (silty)

Annex 8 Discussion on vegetation stratification method

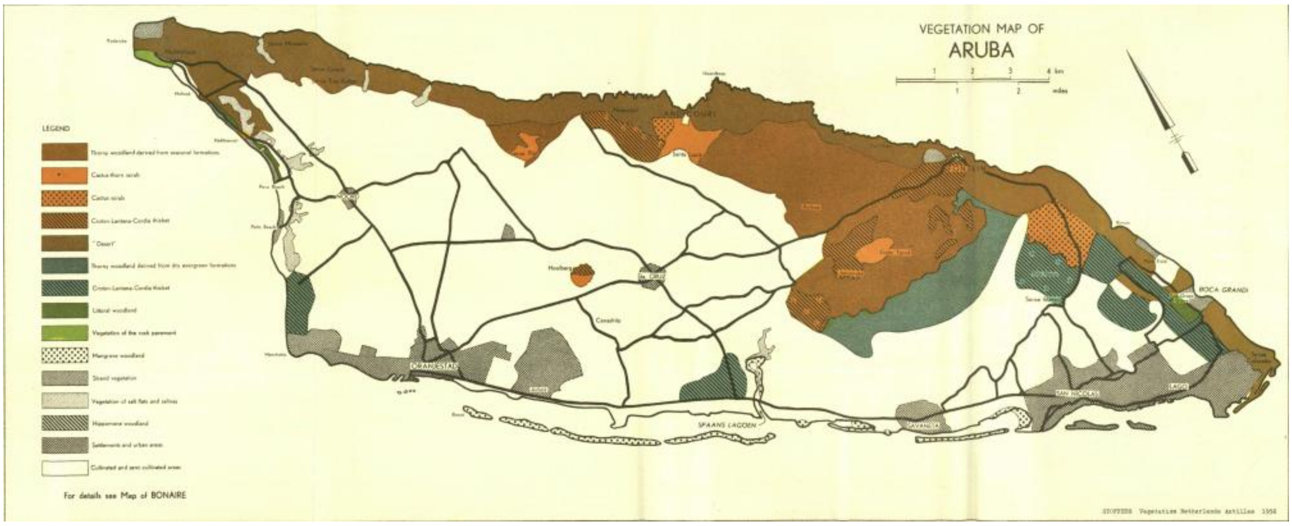
Making a vegetation map is a subjective activity, even when done with an automated clustering method like Twinspan. The mapper's expert knowledge comes into play in delimiting and defining the vegetation types, since natural vegetation is more of a continuum than a set of well-defined types. The results of this research are thus quite different from those of previous researchers, and from the Curaçao and Bonaire landscape-vegetation maps. Though I set out to make a map after the model of the Curaçao map, this one has turned out quite different. I decided against using an automated clustering method like Twinspan, since it works best with a larger number of observation points than I was able to do in a limited time. Also, it would have required identifying the herb and grass species, which proved impossible in the dry season. I wanted to make a map which would give an impression of the link between landscape types and vegetation types, for which I needed to have an intimate knowledge of the terrain. Also, I wanted the map to be understandable for non-biologists, without units named after scientific plant names which only experts can understand. In my opinion, my map does permit comparison with those of Curaçao and Bonaire, because of the similar grouping by geological and landscape categories. Also, the descriptions show in a quick overview which plant types are most common. But it is my wish that the map will be, first and foremost, of practical use in Arikok for planning conservation and restoration activities.

Annex 9 Landscape-vegetation types and surface parameters

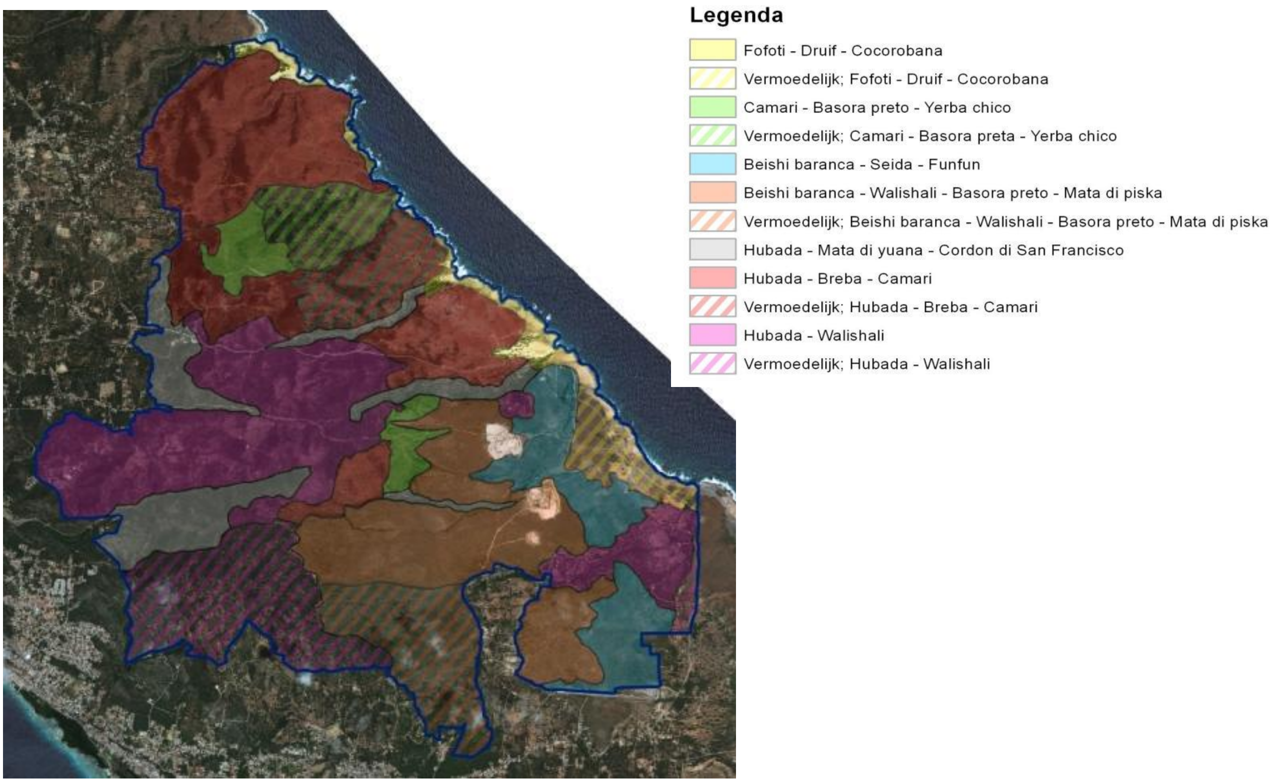
Spatial data (from ArcGIS) for the landscape-ecological types. Slope, roughness, TWI and wind strength are all derived from the DEM. Roughness, TWI and wind strength are unitless and have no absolute value.

Landscape-vegetation code	Landscape-soil equivalent from Grontmij and Sogreah (1968) map (with percentages in brackets)	% of total area of Arikok	Altitude (m)	Slope (degrees)	Topographic wetness index (TWI)	Wind strength
Lt1	Tl (69), Dr (15)	3.9	12	3.0	8.0	45
Lt2	Tm (42), Th (40), Tl (11)	4.3	39	2.4	8.6	45
Lt3	Tm (38), sQu2 (28), Th (18), Tl (9)	2.1	38	2.6	8.5	42
Lp4	Te (90)	1.8	47	8.4	6.4	19
Lp1	Tx (58), Th (36)	14.4	78	3.4	7.7	48
Lp2	Tx (87), Th (9)	3.0	111	3.2	7.6	44
Lp3	Th (81), Tx (15)	4.0	79	2.8	8.2	37
Lo1	Tx (20), Dr (20), Qs (19) Th (17),	2.3	67	13.2	6.5	30
Lo2	Tx (60), Th (18), Dr (17)	1.7	73	7.1	9.2	28
Dw1	Dr (87), Ds (10)	10.6	51	8.9	6.6	45
Dw2	Dr (98)	7.8	80	14.4	6.2	35
Dw3	Dr (99)	8.9	109	11.2	6.4	36
Dl1	Dr (97)	7.5	82	14.0	6.3	23
Dl2	Dr (99)	9.9	84	15.1	6.2	21
Dl3	Dr (100)	1.8	100	14.8	6.1	21
Dw4	Dr (100)	2.1	78	12.6	6.1	27
Dr1	Dr (100)	0.4	46	11.1	9.9	20
Dr2	Dr (100)	0.4	40	10.7	10.2	18
Th1	Qs (95)	3.6	77	10.6	6.6	22
Th2	Qs (69), sQu2 (11), Dr (18)	6.2	85	7.9	7.0	18
Tr1	sQu2 (33), Qs (27), sAb9 (20)	0.8	36	8.9	8.8	20
Uc1	Dr (41), Md (35), Tl (21)	0.2	5	5.4	8.1	24
Uc2	Md (46), Dr (25), Te (14), Sa (9)	0.5	13	5.4	7.9	32
Uc3	Dr (58), IAr2 (39)	0.4	8	10.0	7.5	23
A	Tx (59), Th (22), IAf2 (11)	1.5	52	3.4	8.2	40

Annex 10 Previous vegetation maps



Vegetation map from Stoffers (1956)



Vegetation map from Willemsen (2011)

Annex 11 Experience from a previous reforestation project on Aruba

The May 1997 edition of 'StimAruba Tijdschrift' (StimAruba Magazine, 1997, all in Dutch) has various articles about vegetation on Arikok, rare trees and about replanting. Some details of a previous project are given. From 1962-1975, a reforestation project was carried out at Miralamar in what is now Arikok National Park. There were three parts to the approach: building of stone contour bunds to stop erosion on the hillsides, planting young trees and building small dams in the rooien. The young trees were planted in oil drums as protection against grazing, but were eaten by goats as soon as they grew above the level of the drums. The anti-erosion measures were not so successful for other reasons. It is well worth reading the issue to learn from past experiences about reforestation.

Annex 12 Branch piles as fertile patches

Ludwig and Tongway (1996) describe a simple method to preserve soil and help restore vegetation cover in semi-arid woodlands of Australia, which could be applied in Aruba. Branches are place in elongated piles along contours. The branches trap both alluvial and eolian sediment and water and increase infiltration, creating fertile patches in the landscape. In the study, they improved local soil structure and nutrients, mediated soil temperature, and reduced evaporation. After several years, grass, herb and shrub growth was significantly higher under the piles. Plants under the branches also seemed better able to survive dry times. The technique was successful at improving soil conditions despite maintenance of grazing pressure, although the effects of the branches on plant growth were less marked in the grazed plot. In Aruba, Hubada branches could very well be used, especially on the (degraded) diabase hills, to protect transplanted seedlings.

Figure 4. View of an experimental pile of branches forming a 2 × 5–m treatment plot on which observations were taken.

Source: Ludwig and Tongway (1996)

Annex 13 Bird life of Arikok Park

During the field work, I kept track of birds by way of hobby and to give some extra detail to the landscape-vegetation descriptions. Resident species that were observed frequently and are doing well in the park are: Yellow Oriole, Blue-tailed Emerald hummingbird, Ruby Topaz hummingbird, Northern Scrub Flycatcher, Brown-crested Flycatcher, Yellow Warbler, Northern Caracara, Bare-eyed Dove, Eared Dove, White-tailed Dove, and Common Ground-dove. Migrant species that were observed frequently are: Peregrine Falcon, Osprey and Northern Redstart. Northern Parula and Blackpoll Warbler were both observed once at Rooi Balaster (24/10/2015).

A species that are doing fairly well is the Aruban subspecies of the Burrowing Owl (Shoco). One or two birds were observed frequently around the visitor center, probably a pair nesting nearby. One other bird was observed in a rooi near the road to Arikok. More birds were observed around the park, often on bare hillsides and abandoned quarries in the tonalite area.

Birds that are not doing well in Arikok Park are the Brown-throated Parakeet (Prikichi), Rufous-collared Sparrow and Crested Bobwhite (Patrishi). The latter two were not observed at all during my 4 months on the island. That is surprising for the Rufous-collared Sparrow, which is said to be common on Aruba in the "Birds of Aruba, Bonaire and Curaçao" field guide. I did observe many House Sparrows, which seem to have replaced Rufous-collared Sparrows over the whole island. The Crested Bobwhite is said to be rare on Aruba in the field guide and is said to be nearing extinction, though I heard reports of sightings during my time on Aruba. Although I regularly saw the parakeet around the inhabited areas of Aruba, I did not see a single individual in the park during my field work. This is surprising, as the rangers said it used to be common. The park director indicated that their numbers have been going down rapidly in the past few years. Suggested reasons include drought, boa's and lack of fruit trees due to Hubada takeover.

Annex 14 Explanation of the digital annex

The digital annex consists of one loose document and 3 folders: a folder with additional (hard-to-find) literature (in pdf format), a geodatabase with ArcGIS files and a folder with accompanying ArcGIS layer files.

The loose document, entitled 'Observation points all data.xlsx' contains all the survey point data in an excel file. The file contains a number of tabs:

- All data rearranged: contains all data. The column 'Priority for conservation' corresponds with points marked in figure 8, main text.
- Rare plants incl. geotagged: shows per landscape-vegetation type the frequency that each plant species was recorded, with the rare species marked in orange and red.
- Dw1-Uc3 tabs: same data as the tab 'All data rearranged', grouped per landscape-vegetation type
- Abiotic factors corr: cross-correlation table of the abiotic factors (using data from the tab 'All data rearranged') (same as annex 1, table 2)
- Vegetation types structure (corr) and Vegetation types species (corr): show the vegetation structure and vegetation species cover averages per landscape-vegetation type, with corresponding tabs showing cross-correlation tables of the vegetation types based on these data (for species, same as annex 1, table 1)

ArcGIS_files.gdb contains:

- Aruba_geology_withlegend feature class: digitized geology map from Rijksgeologische Dienst, 1996 (with layer file)
- Aruba_landscapesoil_withlegend feature class: digitized landscape-soil map from Grontmij and Sogreah, 1968 (with layer file)
- Aruba_vegetation56_digitized feature class: digitized vegetation map from Stoffers, 1956 (with layer file)
- Aspect_DEM_Arikok_rescaled raster: aspect (exposition) map rescaled from 1-10 based on the dominant winds: 10 for E facing slopes and 1 for W facing slopes
- Conservation_patches feature class: suggestions for priority restoration areas (main text, figure 8)
- DEM_Arikok raster: digital elevation model of Arikok, created from an old contour line file acquired from the Aruba Department of Infrastructure and Planning (DIP). Served as the basis for the surface maps Aspect, Roughness, Slope and TWI.
- Dust_map feature class: polygons showing areas within 100m downwind of Off_road_tracks

- Landscape_ecological_map: Landscape-ecological map from this project (with layer file)
- LandTenure_Arikok feature class: privately owned land within and around Arikok park
- Observation_points_alldata feature class: point features showing the locations of all 102 observation points, with fields containing all the recorded information (tab 'all data rearranged' from the 'Observation points alldata.xlsx excel file)
- Off_road_tracks feature class: dirt roads and off-road tracks in the northern diabase area digitized from the 2009 satellite image
- Parke_Nacional_ Arikok feature class: outline of Arikok National Park, acquired from ESRI online
- Slope_DEM_Arikok raster: slope map
- TWI_DEM_Arikok_aggregate_rescale raster: topographic wetness index based on 5x aggregated version of DEM_Arikok
- Vegetation_Willemsen: Vegetation map from Willemsen (2011) (with layer file)
- Visibility_DEM_Arikok_rescaled: visibility map created using the Visibility tool (3D analyst tools) in ArcGIS
- Wind_map_DEM_Arikok: hypothetical wind strength map created as a product of the visibility map and rescaled aspect map.

The 'Layer files' folder contains the corresponding layer files.