Landscape series: 1

Spatial Developments in the Aruban Landscape:
A multidisciplinary GIS-oriented approach

Photo: Tree Lizard (Anolis lineatus (Latin), Toteki/Waltaca (local names), Gestreepte Boomhagedis (Dutch)
Photo: Ruud Derix, 2003

The Aruban landscape has undergone many changes in history and still serves as environmental backbone to the society. It plays a vital link and bonds together the social and economic wellbeing and prosperity.
In this paper we introduce and summarize the topics that we describe in detail in a series of six publications on the Aruban Landscape.

2016

Contents

"A sustainable landscape basically suggests a managed balance in local nature that serves the needs of a dynamic society up to the degree that intrinsic environmental values have to be safeguarded for future needs, the latter being point of many misunderstandings"

We like to thank our colleagues Yasmara Pourrier, Marjolein Marquez, Desiree Helder, and Marlon Faarup at the Central Bureau of Statistics Aruba for their general comments on the manuscript

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2016

Towards a balance between socioeconomic and environmental developments in Aruba

This paper is an introduction to a series that describes spatial developments in the Aruban landscape. The aim is to provide information about the environmental issues that we face on our road to sustainability. The condition of the landscape is important as it plays a role as intermediator of environmental influences.
The aim is to review relevant information and make a first step in the establishment of an information database that includes a multiversity of data and relationships that matter to the interplay between the society, economy and the environment.
The series of papers does not pretend to provide a complete description of the spatial developments in the landscape in Aruba, but merely details some of the issues that appear relevant at present.

The scope for a landscape series

International programs developed by the EU and UN urge local administrations to prevent a further breakdown of environmental assets, while international bodies like the Intergovernmental Panel on Climate Change (IPCC[1]) make assessments and advise for instance on climate change.
It is an accepted view that global climate is changing and that, entangled in our way of living, there is harm to the environment that is to bounce back and bring immense costs to the overall economy and our well-being (IPCC, 2007) (World Economic Forum, 2016).
The General Assembly of the United Nations, aware of the incapacity of separate states to counteract these developments, proclaimed a set of Principles to serve as a guideline to local governments (RIO20+, 1992). The recommendations urge States, key sectors in society, and the population to take the health and integrity of the earth's ecosystem serious, and attempt to achieve sustainable development with environmental protection as an integral part of the development process (*RIO20+, Principle 4*).
Environmental bodies like the IUCN also advocate an integrative and global approach to safeguard for instance the landscapes and its biodiversity. Local cooperation and information gathering is critical to find a common base for support and to specify the allocation of time and money from international programs.
Recently, the Aruban government made the commitment to put efforts in innovation, energy-efficiency and sustainable actions (Aruba, 2011)[2].[3] The prime challenge is to become less dependent from the import of oil-based fuels, given that the production of energy and drinking water depends heavily on the import of these fuels. Local initiatives such as a 'smart community' project and the 'solar panel roofing' at the airport are initiatives that propel further public interest. To help implement prevention, control, incentive and disciplinary measures, sustainability also requires the organization of information exchange structures and the continual monitoring of events (Aruba, 2013).

Information from land use and resource exploitation serves an important instrument to gain perspective of the changes in the environment (EEA, 2011). Globally, Aruba plays an insignificant role in the environmental human footprint but at the local and regional level the impacts on the environment do count. Aruba's natural scenery not just serves intrinsic environmental values but is highly valued by the (international) society and is recognized as a prime asset by the tourism industry (Murphy, 2011). A number of local trends cause concern, such as for instance the fragmentation and loss in habitats and biodiversity, the eutrophication of marine waters and the contamination of land surface areas[4]

The topics we cover in this series

The landscape has a strong historical and geological component, but the landscape also reflects the choices made when striving for prosperity. To improve our understanding we summarize information from different sources and describe the historic developments in Aruba from the time after colonial discovery in *Landscape series no. 2*: "*The history of resource exploitation in Aruba*". Also, we summarize information about the geological origin and geomorphology in *Landscape series no. 3*: "*A Review of Geology, Climate and Hydrology in Aruba*". The third paper in *Landscape series no. 4*: "*The suburbanization of the Aruban Landscape", provides* more detail on the relationship between geology and the extent of agriculture in early 20th century.

The current spatial developments follow each other in rapid pace and although there are still wildered spaces left, a suburban progression is recognizable. Already, we see a trend from the typical low-floor residential building towards two-storey accommodations. We describe these trends in separate papers and cover the issues of suburban developments also in *Landscape series no. 4*: "*The suburbanization of the Aruban landscape*" and, the changes in household accommodation and in the way we live in *Landscape series no. 5*: "*Housing and accommodation in recent decades in Aruba*".

In a final paper we cover some events that reflect a disharmony in the socio-environmental relationship. The pressure from the human footprint on the environment is reflected in the household concerns that we highlight in high spatial detail in *Landscape series no. 6*: "*Conflicts between the Economy and the Landscape in Aruba*".

[1] http://www.ipcc.ch
[2] Green Gateway: Economic vision and policy Aruba 2011-2013
[3] Binden, Bouwen en Bestendigen. Regeerprogramma 2013-2017

[4] We refer to International reports from [www.birdlife.org], [www.cepal.org], [www.ec.europa.eu], [www.dcnanature.org], [www.cepf.net], as well as local/regional studies and reports [(Bak, 1987), (Gast, Reef Care Curaçao Contribution no. 5: Nutrient Pollution in Coral Reef Waters, 1998), (Haapkylä, Ramade, & Salvat, 2007), (Baker, Glynn, & Riegl, 2008), (Del Nevo, 2008), (Lapointe & Mallin, 2011), (van Buurt & Debrot, 2012), (van der Burg, de Freitas, Debrot, & Lotz, 2012)].

Alert levels

To give some guidance, we examine the main global actors of present day environmental threats and evaluate whether they deserve local prioritization as well.

A review of the most urgent environmental threats of our time is put against a scale of pressure (Foley, 2010). International studies show that *Climate Change* due to elevated levels of predominantly CO_2 concentrations in our atmosphere, *Loss in Biodiversity* and the *Overflow of Nitrogen and Phosphor* in our atmosphere, land and oceans have already crossed the outer boundaries of what is thought to be safe. These processes thus deserve our highest local priority and attention (McKibben, 2010).

In Table 1 we check marked the nine major global threats in order of estimated local significance[4] in Aruba. Such local prioritization is tentative as there are only few local studies to support the prominence of the processes involved. We will discuss these local processes next in more detail.

1. Biodiversity loss	✓✓✓
2. Land use	✓✓✓
3. Freshwater use	✓
4. Stratospheric ozone depletion	✓
5. Nitrogen and phosphorus overflow	✓✓
6. Aerosol Particle concentrations	✓
7. Ocean acidification	✓
8. Chemical pollution	✓✓
9. Climate change	✓

Table 1 In total nine key environmental processes have been acknowledged globally that deserve local attention. These nine processes are based on research conducted by an international group of renowned scientists (ScAm, 2010).

Although *Climate Change* incorporates a major global problem, its local role of significance to environmental processes may be limited. Nevertheless, to comply with the international community, *Climate Change* is to be considered a topic that deserves high local priority as well. Problems like the *loss in Biodiversity* and *Nitrogen and Phosphor overflow* however do pose a direct threat to the local Aruban environment. We will discuss what above processes may entail for the local situation.

Climate Change

'Climate Change' in terms of a disturbed CO_2 balance comes with an interesting challenge in Aruba as, aside from the dependence on oil and the negative impact from the burning of fossil fuels (that causes the release of carbon dioxide in the atmosphere), there is detriment to the coral communities and unrestricted logging of trees that does not adhere to a restauration of the local carbon balance either (carbon sequestration takes place via the growth of coral communities and of vegetation). In the past, Aruba has been famous for harboring the largest oil refinery facility in the world (Ridderstaat, 2007) and with these oil refinery processes likely has been a major contributor to the release of greenhouse gasses. After the closure of the oil refinery, the island adds little to the global impact on climate change.

On the contrary, the local authority has taken the initiative to lower and even aim to completely exchange its oil dependence for more sustainable alternatives. Future actions in the environmental domain might be in line with this renewable energy strategy and advocate the use of *greenhouse-gas-friendly* products or implement local *reforestation programs*.

Loss in Biodiversity

With regard to the '*Loss in Biodiversity'*, the ongoing residential and economic development in Aruba is responsible for a general loss in critical natural habitat, species and communities. However, while on the one hand such development seems to aggravate an overall loss in species, in particular to those species that are considered keystone species that help maintain the food webs of local terrestrial or marine ecosystem (Barendsen, et al., 2008), other species' abundance and composition may benefit from a shift in available types of food or the protection within the realms of human inhabited areas against wild predators such as from the Boa *constrictor*. In particular, the so-called culture-follower species, such as some birds are abundant near human inhabitation (Derix et al, 2011).

In regard to habitat degradation, the spatial extent of human agricultural presence a century ago is actually similar to the extent of economic development today (Derix, 2016d). The loss in critical land-based natural habitat, that is so evident today, mainly concerns the wildered agricultural terrains (locally referred to as 'Mondi') that exist for less than a century during which time of course nature may well have been at the brink of reestablishment. In particular the species that are characterized by their historical links to the Aruban culture are under the influence of the dramatic changes in the landscape.

Nevertheless, as elsewhere (Mcdonald, Kareivab, & Forman, 2008) it is perceivable in Aruba as well, that with the changes in the landscape there is a critical *loss in biodiversity* and *in habitat* albeit that only sparse information is available about species presence or abundance in the more distant past. Whereas newcomer species seem more abundant now than ever before (Derix et al, 2011), other often endemic species shift towards the edge of their existence and some have become extinct already (Barendsen, et al., 2008). Loss in food and nesting sites, competition by invasive species, caging and even predation by cats, dogs and the Boa *constrictor* (including by humans) all is part of the changing natural environmental setting and exemplifies the complexity of the problems that local species (animals as well as plants) face.

Network of corridors between habitats

There is a necessity to strengthen the robustness of remaining local ecosystems. Still economic developments pose a direct threat to the few remaining patches of mangrove forests or coral reefs along the coast, whereas mangrove and coral reef habitats can be considered the most threatened ecosystems in Aruba. We observe such situation on land as well, as remaining patches of (relatively) undisturbed ecosystems have become insufficient in size to serve as suitable habitat for the species survival unless we find a way to interconnect these areas and create a *network of corridors* (on land and at sea) that enable wildlife to disperse or find shelter and food.

The establishment of a large infrastructure of ecological corridors[5] can be an instrument to preserve biodiversity within the expansion of socioeconomic developments.

Overflow of Nitrogen and Phosphor

The potential *'Overflow of Nitrogen and Phosphor'* has received little local attention yet but might be significant in regard to the small island setting and the high population density (Gast, 1998) (Howarth, et al., 2000). It will be interesting to investigate the level of dissipation or binding by nutrients (and contaminants) to, for instance, the calcareous limestone soils and investigate in what degree they disperse with the ground water and rainwater runoff and may have a direct effect on the coastal marine ecosystems. Coastal residential sewage and fertilizers (amongst other sources) may certainly aggravate nitrogen levels and may even overthrow the soil binding capacity. Interesting to note is the importance of irrigation fields and areas like Plas Bubali to sequester free N compounds from treated wastewater before these can reach the sea (Buurt, 2008).

Land use

In Aruba, like elsewhere, societal, economic and environmental interests compete for available space and there is a *historic* and even a *geological component* embedded that defines our current opportunities and challenges to attain sustainability.

Housing, infrastructure and economic expansion have created, besides the loss in natural habitats, a landscape with environmental issues such as waste, litter, pollution, erosion, noise and other sources of human disturbance.

Aruba has a relatively high population density (ca. 602 persons/km^2 in 2014) with limited backcountry left, and aside from the protected National Parke area, there is reason for concern about the quality of the remaining landscape. In recent decades the population and new construction for housing increased consistently (Derix, 2016d) aggravating the human footprint in Aruba.

Waste, contamination and nutrient enrichment

In Aruba, '*Land use'* is likely described together with '*Ocean Acidification'* and '*Chemical Pollution'* (processes 7 and 8 in Table 1). For instance, on a relatively small surface area of about 180 km^2, there is an accumulation of waste from all imported products and goods produced by more than 100.000 inhabitants and approx. 1.7 million visitors per year in 2013 (almost 1 million stayover visitors, equal to 7.2 million visitor overnight stays, and almost 700,000 Cruise Passengers) (CBS Aruba, 2014). Obviously the goal to process and dispose such amount of waste sustainably is a challenge for the society and for the environment. Until recently litter and waste accumulated in one giant open waste dump directly bordering the sea, but last year the situation has improved considerably. A modern large waste gasification plant is designed to incinerate all types of waste while the gaseous residuals are meant to serve as an alternative fuel source for the water production plant nearby. Not yet accommodated however is the *liquid disposal* of nutrients and contaminants (including those from coastal cesspools) that locally leak into our soils and waters. The prolonged contamination of soils (in particular along the coast on the calcareous permeable limestone plateaus) and the leaking of nutrients into the ground- and coastal waters point toward a difficult problem that threatens the quality of coastal waters to sustain a healthy coral reef and mangrove ecosystem. We like to elucidate some of these processes a little further.

Clear coastal waters, white sandy beaches and a rich coral reef ecosystem exist as part of a wider healthy ecosystem that developed under local geological and climate conditions. Residential and economic activities however induce an environmental change that manifests not just on land, but also in surrounding waters, such as an increase in litter and pollution but also by disturbance and detriment to the coral communities along the coast (Chabanet, et al., 2005) (Goreau & Thacker, 1994) (UNEP, 2003) (OSPAR, 2010). The island setting is small and characterizes a low-level nutrient environment and a high nutrient recycling adaptation, i.e. local ecosystems have evolved to deal with an incidental abundance of nutrients to incorporate into the food web very efficiently. However, even robust systems are susceptible to an unremitting rate of nutrient enrichment and contamination and may shift away from their stable state. The current rate of change appears to overthrow the local ecosystems' resilience (M.Nystrdm, Folke, & Moberg, 2000).

An assessment of subterranean hydro chemical processes as well as processes on land is relevant to gain proper insight in the changes at sea and along the coast.

The example shows a reality of the complexity of processes that underlie specific themes. An environmental issue is most often multifaceted and requires policy and action at different levels and disciplines. The idea behind this '*series on the landscape'* is to inform about this complexity and thus encourage policymakers to define budgeted goals in this area.

Safe marine waters

Not covered in this series, but an issue worth mentioning, is the threat from accidental pollution of the Aruban marine environment with potential harm to the tourism economy, caused by large vessels that pass or anchor within Aruban territorial waters at less than 13 km off the southwest coast[6]. The sea surrounding Aruba is an area of intense marine traffic[7] and Aruban waters are still considered a safe haven in the region. An international corridor for shipping exists between Aruba and Venezuela beyond the distance of 3 miles (approx. 5.5 km) from the coasts[8]. Oil tankers often reside within Aruban territorial waters close to the coast as they await approval to enter Aruban transshipment piers, reside under maintenance, or, stay purposely in Aruban waters (foreign vessels) to await final destination. Local authorities may enact legislation when vessels enter the 3 mile zone, but, even outside this zone, intense traffic and anchoring oil tankers in general pose a potential risk to the Aruban coastal ecosystems. Information about incidences of oil pollution in our near coastal waters is not yet collected systematically.

[5] http://www.sicirec.org/definitions/corridors

[6] www.defensie.nl Topic: maritime boundaries of the Caribbean

[7] www.marinetraffic.com

[8] Border Treaty between the Kingdom of the Netherlands and the Republic of Venezuela (Trb. 1978, 61; 1979, 11)

Previous assessments

On several occasions there have been environmental studies focused on taking inventory, installing monitoring processes, building a system of environmental indices or implementing information exchange structures (Hengst & Rehorst, 1995) (Belle, 2001) (A.J. Schilstra and J. van der Perk, 2001) (Perk, 2003). These studies were planned in a broader scheme of environmental assessments together with respectively the University of Nijmegen and the University of Groningen in the Netherlands, but the initiative remained without follow-up. It proved to be difficult to recover the reports of these studies but the underlying data were lost and with it some important baseline data. Occurrences like these show the weakness of information exchange and stress the importance of storing and sharing data and reports in an organized network of databases and libraries.

After the disintegration of the Department VROM[9] in 2002, the Department of Public Works (DOW), Department of Infrastructure and Planning (DIP), the Cadaster (DLV), and the Institute for environmental monitoring (IVM) shared the responsibility of environmental matters for over a decade. With the launch of the section of Environmental Statistics in 2012, the Central Bureau of Statistics made a first start to gather available environmental information from different disciplines and stakeholders. Thematically, this information is disseminated in a series of publications on energy, traffic, biodiversity and landscape (www.cbs.aw/environment). In 2013, a more dedicated authority for environmental matters the Department of Nature and Environment (DNM) was established to advocate the role of nature in society.

In 2008, a Spatial Development Plan (ROP, 2009) was completed to streamline the spatial extent of societal growth and economic change and be able to acknowledge local environmental values. The plan developed by the Department of Spatial Development and Infrastructure (DIP) is considered a milestone in the planning of sustainable growth with inherent environmental protection, although not all environmental issues could adequately be covered. But it is an important first step in spatial planning and the incorporation of as well urban as environmental interesting areas. The plan depicts regions for nature restoration, housing projects, economic expansion, agricultural development, and infrastructure and so on. Embedded by deliberate rules and regulations (ROPV) the plan was meant to act as a guideline for spatial development while it still remained adaptable to changes in the definitions of local areas. The formalization into a series of binding rules and regulations that would integrate juridical support and measures of control, however proved to be difficult (Arends, 2009). The plan in optima forma is meant to provide sufficient juridical stronghold to maintain future spatial developments in Aruba in line with nature conservation efforts and sustainable growth of economic and social well-being.

9 VROM (Directie Volksgezondheid, Ruimtelijke Ontwikkeling en Milieu). Directorate of Health, Spatial Development and Environment.

Meanwhile, from within the tourism industry concern was ventilated about the future of the tourism industry in perspective of a worsening of the condition of the landscape and local environment. In 2011, a '*Forum for the Future of Tourism in Aruba*'[10] concluded on the basis of specialists' reports that (amongst other factors) *the restoration of environmental forces and pristine natural Aruban settings* is of major concern to be able to compete internationally for tourist visitation (Murphy, 2011). There was realization that current *land degradation had gone too far* and that the *'pristine' Aruban countryside* was losing its tourist attractiveness and competiveness with other islands in the region. The landscape and natural environment was not simply an asset that would be always available, but required consideration and maintenance. It was necessary to engage more than simply to keep the environmental impact in check or explore the local carrying capacity of available land to capitalize further growth.
However, it is no easy task to uphold an image of a typical Aruban landscape or pristine nature in the complex of interrelationships between societal and economic interests. Ecological restoration and sustainability is more than a simple make-over of the areas involved and includes a change in consumption patterns, land-use management, public awareness programs, environmental monitoring, research and legislation, and an information infrastructure.

The use of GIS[11] to analyse environmental data in high spatial detail

A *system of environmental indices* has often been called for to help asses and monitor ongoing environmental processes. Similarly, at the interface between economy and environment *ecosystem accounting* and *environmental valuation* (of local nature resources) have been proposed to offer means to better understand the value of the local environment in terms of embedded economic costs and benefits.
To develop such assessment and help identify alert levels and indicators requires an open and dedicated local and regional system of information exchange. The interest for cooperation in data gathering and the support from research is of course imminent[12]. Momentarily, the implementation of an integrated system of socioeconomic and environmental indices is not feasible as a system for environmental information exchange is not yet installed. Also, we are far away from defining alert levels and local tipping zones (or local threshold values). But, with the information available we may already recognize and define prime local '*alert types*' similar to those as mentioned in Table 1 at the global level.

10 http://arubatsa.com/atsa-tourism-leaders-review-factors-affecting-tourism/

11 A GIS (Geographic Information System) is a computer-based tool that enables the linking of information from many different fields on the basis of a common geographic component. Layers with information from for instance, socioeconomic, environmental and topographic surveys are brought together on a common spatial scale. Linked in this manner, the GIS system provides additional information and opportunities for research.

12 From: Beyond GDP_EU-2009

In its role of carrier of information the section of Environmental Statistics of the Central Bureau of Statistics in Aruba is dedicated to improve however the dissemination of environmental information. The aim is to build and enhance an integrated structure of monitoring systems to collect information from stakeholders and own research in order to better serve requests from policy makers and other stakeholders.
The current landscape series accounts the status of information in relation to landscape characteristics and emphasizes the lack of information on several subjects.
In order to be able to construct a system of environmental indices or set up a system of energy, land-use or water accounts, for instance, more efficient monitoring systems, data collection and harmonization is necessary.

Environmental information is strongly related to a given time and place, so it is important for the better understanding of underlying processes to acknowledge the specific circumstances during data collection and analysis. For example, we may use satellite images to determine the changes in vegetation growth or land coverage, but we have to compare images from similar seasonal conditions. GIS (Geographical Information System) technology is an essential tool to enhance the quality and productivity of environmental studies. For this reason, many environment statistical agencies worldwide are intertwined with a GIS department.

The spatial embedding of data

Spatial embedding of data allows information from different fields to become linked by a common geographical component and to describe issues at the interface of society, economy and the environment from a multidimensional perspective. We have initiated the following approaches to improve the support of environmental data gathering, exchange and dissemination:

The national Grid System (ARUGRID-System)

Environmental data cannot always easily be linked to socioeconomic data because both fields are to some extent spatially separated. Also, environmental data often refer to concentrations or areas without a strict border. A common solution is to disseminate socio-environmental data on the basis of a reference raster of grids. Areas are split in small squares and different data can be presented similarly in an aggregated manner. Modern GIS techniques offer a wide range of possibilities to analyze spatially distributed environmental and socio-economic data, but the use of grids is easily understood and directly convertible to/from other analysis software.
The EU, in cooperation with the EEA (European Environmental Administration) encourages the use of Grid reference systems to their federated states and are currently working on a proposal for an ISO standard: "EEE recommends the use of multipurpose ETRS89 Lambert Azimuthal Equal Area 52N 10th grid.
The European Environmental Administration has developed a tool (EEA Fishnet Tool v1) to create a grid using ESRI ARCGIS software. With the tool one can create a polygon or line 'shape file according to the EEA standards of an ETRS-LAEA grid.
In Aruba, we cannot use this same grid because we are too far to the West, but the department of environmental statistics already used a similar projection of geographical data as in the EU throughout its earlier analysis. At present, there is no *official Grid Standard* for Aruba, but the '*Aruba Grid System – ARUGRID* (prep, 2016g) may serve this purpose.
In a number of publications, the ARUGRID System has already been used to disseminate some small sets of environmentally oriented data obtained from the 2010 Population and Housing Census (Derix, 2013a) (Derix, 2013b) and the Aruban Bird Count (Derix et al, 2011). In this series on the Aruban landscape, we will continue to disseminate our results in use of the ARUGRID System.
The *Central Bureau of Statistics* of Aruba (CBS) proposed a number of additional initiatives to ease data collection and data exchange and to improve the quality of up to date relevant information (Derix, Opportunities and Challenges in Environmental Statistics in Aruba, 2014), such as will be necessary to complete the monitoring system layout.

The National GIS Platform

In cooperation with the Departments DLV (Cadaster), DIP (Infrastructure and Planning) and the DOW (Public Works) (Derix, 2009), a plan is proposed to establish a National Spatial Infrastructure, the "*National GIS*" project. GIS is to become the main instrument of collaboration to create, store and share relevant information on the basis of the spatial component. The maintenance of information and the interchange between participants is well-supported in *a network of GIS databases*. The original proposal (Derix, 2009) to enhance collaboration and establish a national GIS infrastructure is conform modern ideas of information exchange. Similar enhancements of the information infrastructure are in preparation in other Caribbean islands as well (URISA, 2014). Consequently, new opportunities arise to connect and build on knowledge transfer on the international scale as well.

The use of smart imagery interpretation technologies

Aside from the infrastructure of cooperation, much of the information we need to establish is missing or incomplete. As history learns, in a small island community setting it is difficult to monitor, collect, aggregate, and disseminate all the relevant information by own means and also keep an up to date and complete database as well over the years. Information gathering and integration requires more time and resources than are available and high accuracy in terms of data consistency and reliability. One way to meet these requirements is the use of *smart imagery interpretation* technologies. The idea however requires external funding and support.
The *semi-automatic interpretation and digitalization of satellite based landscape imagery* would deliver very relevant local data that might otherwise not be collected. This initiative from the CBS was integrated into an EU funding proposal, headed by Netherlands Organization for applied scientific research TNO and its Caribbean Branch Office CBOT in Aruba, that incorporated the idea into a study on *land-based rainwater runoff and groundwater pollution on coral reef ecosystems* (WACUP, 2014). The final setting included a partnership between 25 international research institutes in Europe. Aruba would profit not only

by investigation of the islands' rainwater run-off processes and its effect on the coral reef ecosystems, but equally important, would install along the way an effective information exchange instrumentation. Leaning on the expertise and support from international research institutes, this project and the planned National GIS setup would fit well the interest of local authorities.

Landscape series: Summary and Conclusions

In ***Landscape series no. 2*: "*The history of resource exploitation in Aruba*"** (Derix, 2016b) we created a time window and a short overview of the exploitation of resources and the impact thereof on the landscape. Next, we will briefly summarize its contents; however, for more detail and readings we refer to the aforementioned paper.

Available resources often propelled the economy but sometimes only made it possible to cope with the harsh conditions of local subsistence. Periods of grazing, deforestation, cultivation and mining subsequently had their impact on the face of the landscape while the newly created conditions triggered new opportunities for wildlife and for man. In essence this is still true for today's situation, be it that the fast pace at which new conditions occur infringes with the time left to preserve the remaining nature.

In recent decades there has hardly been any environment-oriented monitoring program, so we do not know exactly the distribution of local species and habitat requirements. Without doubt, there has been a notable change in the Aruban landscape by the defragmentation and loss of species' habitat due to new infrastructure and construction. This is not the first time, however, that the Aruban landscape underwent drastic changes.

From late 16th by the Spanish and mid-17th up into late 19th century by the Dutch, the red dye-wood Haematoxylon *brasiletto*[13] was a solid source for wood (dye) export from Aruba to Europe. The harvest of these and several other species of woods from Aruba characterized a long history of deforestation. The local dye-wood is repeatedly named Brazilwood but todays' scientists prefer to use the name *Peachwood* (Cardon, 2007) to keep from confusion with the so-called *true Brazilwood,* Caesalpina *echinata,* originating from Brazil. Unfortunately, we miss information about the coverage and extent of dye-wood habitats in the distant past. The favored habitat in Aruba may have been on the limestone terraces along the coast as there is a preference for calcareous soils but specific information is lacking. Today, only remnant trees of Haematoxylon *brasiletto* remain in Aruba on a few locations.

The long-term harvest of dyewood (and other woods) and the grazing by large herds opened the face of the Aruban landscape and created exactly the right conditions for further development with Aloe and mixed agriculture. At the end of 19th century, all along the coast, most limestone terraces were readily cultivated with Aloe. After wood became economically unimportant for export, the harvest of woods continued, either for construction, as local firewood or as firewood for the lime kilns. Woods were cut in Aruba up into the 20th century and old trees actually are remorselessly cut even today.

Current economic and residential growth created a suburban landscape that in spatial extent is about the same as the agricultural landscape at the start of 20th century (Derix, 2016d).

We made a comparison between the land in use now and at the beginning of 20th century, exactly one century ago. Wildlife was already in retreat by the destruction in habitat, by hunting, fertilization and chemical pollution. Its use for agriculture and later also for the oil industry intensified the draining of aquifers and groundwater[14] and may have intensified a salinization of the groundwater as well. Today, in the inhabited areas the opposite may be true, as waste water and irrigation constantly leak into the soils. Residences offer rich garden systems with plenty of water, shelter and food but the soil and groundwater enrichment is likely to influence the food chain and favor some species above others (Zhang, 2015) (Mcdonald, Kareivab, & Forman, 2008). More so than in the past, international trade and mobility introduces exotic species that in the newly disturbed environments compete successfully with the local endemics.

In 1950, the Dutch zoologist Freylinck stressed in an inventory of local species in Aruba (Freylinck, 1950) the extinction of several bird species, amongst which the Aruban Green Parrot (Amazona *barbarensis*) and the Ala Blanco (Columba *corensis*). Also, he noted, that other species had become rare. The landscape he describes was very dry and almost without any vegetation. The land in the west and the northeast he even depicted as a stony desert.

Today, another number of species have become rare whereas some have become more abundant. The key stone species[15] generally have difficulty to survive (Mcdonald, Kareivab, & Forman, 2008). For instance, large flocks of the Caribbean parakeet (Aratinga *pertinax* arubensis) have 'always' been a common sight in the past, but nowadays the parakeet is seen mostly in pairs or in small flocks of three to four (Derix et al, 2011). It may be that this is an adaptation to todays' more dispersed allocation of food resources. The majority of the large orchards with fruit trees and large crop fields have been fragmented or lost, leaving the birds without the local abundancy of food

[13] Note: Haematoxylum *brasiletto* is very rich in *brazilin* (Dapson & Bain, 2015). Brazilin is obtained from the heartwood of the tree and acts as precursor to the red colored dye *brazilein* when it is oxidized. In Europe, the red dye colorant was welcomed in early colonial times to replace more expensive colorants from the East. But little is known about the many different other uses of the colorless component *brazilin*. Haematoxylum *brasiletto* is known for its uses in textile and histological staining (Cardon, 2007) but its extracts are also used for medicinal treatment of diabetes, blood pressure and gastrointestinal problems. Brazilin is also known in pharmacology for its antibacterial properties and use as antibiotics, antiobesity, antioxidant and antitumor remedy as for many other purposes (Dapson & Bain, 2015). It might be worth to explore whether a reforestation with the typical local dye-wood might offer opportunities for export as well.

[14] The pumping of subterranean fresh water sources was necessary for the oil refining process (Ridderstaat, 2007).

[15] A keystone species is a species that plays a major role in the food web and local ecosystem

sources. We do not observe many small flocks either, so it is reasonable to assume that besides the change in diet and food availability the parakeets do actually have difficulty to survive for other reasons as well. Influences such as the loss of social nesting and social sleeping sites or the predation by the Boa *constrictor* may also contribute to their decline. Moreover, still today, young birds are caged and old nesting trees are cut as they may harbor termite nests (parakeets typically build their nest in the tree-hollow nests of termites) or because the land is cleared for construction (which is often not the case after all).

In ***Landscape series no. 3*: "*A review of Geology, Climate and Hydrology*"** (Derix, 2016c) we bring perspective to current environmental developments in terms of geological (Busonjé, 1974) (Beets, Metten, & Hoogendoorn, 1996) and (paleo) climate conditions (Hodell, et al., 1991). We place in a simplified manner the geological history of current landforms in a historical perspective and describe its effects on the current hydrology and topology of the landscape. This information is relevant for the understanding of the current environmental issues in the local settings.
We exemplify the strong relationship between geology and landscape and interpret as a case study the geological information from Beets (1996) and Busonjé (1974) with the information from the topological Werbata-Jonckheer map that describes the situation in 1909-1911 (Werbata, 1913). We refer to Krogt (2006) for information about the maps from Werbata (terrain surveying W.A. Jonckheer). The relation between geology and early land use is substantial for modern spatial developments, as it determined the layout for todays' construction, surface- and groundwater management, rainwater runoff and exposure to flooding that in turn relates to eutrophication and contamination of local soils and marine waters. Currently an inventory is being made of the extent of agricultural activities that will make it possible to calculate an index of land cover. For further reading, we refer to the paper.

In ***Landscape series no. 4*: "*The suburbanization of the Aruban landscape*"** (Derix, 2016d) we detail the subsequent shifts in economic interest in the different regions in Aruba. The growing population brings along a wave of construction that started in the early 20th century in the south-east (influenced by the need for workers in the oil refinery) and gradually displaced towards the north-west (influenced by the booming tourism industry). Early land use and infrastructure however has set the layout for today's traffic congestion and problems in infrastructure and to some degree still hampers the spatial developments. The shift in economic activity towards the north-west has created a hotspot for business activities and land development projects. Many of the employees, however, cross the full length of the island on a daily basis for their trip to work. The road infrastructure is not designed to cope with so much traffic, causing traffic jams and harm to the environment by fuel use, car exhaust, and the construction of new roads. The construction and expansion of houses has shown a declining trend, however the construction of new apartments has increased. Interestingly, while total investment in new residential construction has dropped, the investment per square meter has risen. A change is evident in housing characteristics and in the way we live. For further reading, we refer to the paper

In ***Landscape series no. 5*: "*Housing and accommodation in recent decades in Aruba*"** (Derix, 2016e) we analyzed the densifying pattern of residential construction, the changes in housing conditions and the use of construction materials. We observe a striking difference between the northern and southern region in Aruba in the use of air-conditioning systems. There is also a trend towards smaller houses with fewer rooms and smaller plots, but often with two or three floors and using different construction materials. For further reading, we refer to the paper

In ***Landscape series no. 6*: "*Inconveniences in the home neighborhood in Aruba*"** (Derix, 2016f) we analyzed the distribution of household inconveniences to reveal aspects where the economy, society and environment fringe. Also we go into detail on the environmental hazards that lie hidden in our daily household consumption patterns. For instance, the daily disposal of solvents and liquid waste in the direct surroundings of our living environment comes with an accumulation of nutrients and contaminants and a long-term effect on the quality of soil and groundwater as well as surrounding marine waters and ecosystems. For further reading, we refer to the paper
We used the National Grid Reference System to describe at the finest spatial detail some of the related processes. We were able to define the areas that experience flooding after heavy rains and where 'air pollution', 'noise', 'dust', 'litter', 'stray dogs' or 'car wrecks' cause inconveniences in the neighborhood. The spatial analysis with GIS technology proved to be very relevant (despite the limited availability of GIS analytical tools in the ESRI ArcView version) to understanding the local dimensions of problems that have a social, economic and environmental component.

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