Nexus interventions for small tropical islands: case study Bonaire

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Introduction and aim:

Pressures on NEXUS domains (water, food, energy, ecosystem) are particularly increasing in small tropical island developing states, due to a combination of limited availability of space and resources, ever growing human populations, and climate change. This requires an integrated, innovative and sustainable management approach to secure food, water, and energy supply and ecosystem services for future generations. In this project we aimed to develop such an integrated management approach (on the longer term) for small tropical island developing states, using Bonaire as a case study. The first activity was to identify feedback loops, and explore the need for interventions given the NEXUS philosophy.

Wageningen Marine Research

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SUBJECT
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The economy of Bonaire is vulnerable, depending mainly on its valuable natural marine resources which form the basis of its tourist industry. However, tourism-related coastal development puts pressures on ecosystem resilience through habitat loss, waste production, and water and energy use, enhancing feedback loops with negative consequences within the nexus. In addition, Bonaire is currently being confronted with an increasing population via increasing numbers of tourists visiting the island and immigration. Moreover, it is dependent on the import of food, the production of water and electricity from fossil fuels (and high related costs). To be more self-supporting in terms of food, water and energy production and to reduce the according negative nexus-feedback loops, interventions are needed. Furthermore, the current practice of extensive animal husbandry leads to deforestation, desertification and disruption of the hydrological cycles through overgrazing by free-roaming goats. This in turn leads to impacts in other nexus domains e.g. loss of topsoil (erosion), reduced groundwater replenishment, desertification and extinction of plant species and loss of biodiversity. Overgrazing and coastal development have contributed to severe deterioration of the island's fringing coral reefs and mangrove habitats, which are the main attraction for the tourism industry, crucial to the island's economy. On top, climate change presents exacerbating nexus challenges to Bonaire because of its small geographical area and generally low altitude. The associated challenges from sea-level rise, altered rainfall patterns, and storm-surges threaten any island's sustainable development.

Activities and results

Main activities in 2018 were to

- create a WUR project team covering different expertise.
  - 2 meetings were held to discuss the Nexus domains, knowledge available and needed.
- Consultation of stakeholders on Bonaire during workshops on Bonaire- see table below. Workshops and meetings aimed to introduce NEXUS “thinking”, and identification of obstacles, interventions needed, and knowledge needs.
- Drafting of factsheets/policy briefs (Table 1).
  - Input for the eight Nexus-factsheets was obtained by reviewing the literature and by organizing workshops and meetings (held between 14-10-2018 and 19-10-2018) with various organisations on island (see Table 2). In these summary reports, short descriptions are provided per Nexus domain: water, food (either from the ocean or from land), energy and ecosystem. In addition, a Nexus-factsheet for tourism and for tools was drafted, the first because of the large importance of tourism for the economy of Bonaire, and impact on the other nexus domains, and the second because innovation in science (tools) can be of large importance in identifying interventions. In each factsheet, the current status is described, together with main drivers of change, future ambitions, and possible Nexus interventions to achieve these ambitions. Special notes on governance issues are made. The factsheets are included as annexes. Although Bonaire has its own dependencies and structures, the provided Nexus solutions may exemplify for many other small tropical islands in the Caribbean and elsewhere.

Table 1 Factsheets drafted. These can be found as annexes to this letter report.

factsheetnumber	Theme	Authors	Reviewer
1	Introduction	Matthijs van der Geest[1], Diana Slijkerman[1]	Dolfi Debrot[1]
2	Water	Diana Slijkerman , Matthijs van der Geest, Dolfi Debrot	Dolfi Debrot
3	Food from the ocean	Dolfi Debrot & Sander van der Brug[3]	Diana Slijkerman, Martin de Graaf[1]
4	Food from the land	Matthijs van der Geest Diana Slijkerman	Dolfi Debrot
5	Energy	Matthijs van der Geest Iago Teles[4],	Diana Slijkerman
6	Ecosystems	Diana Slijkerman, Dolfi Debrot, René Henkens[2], Matthijs van der Geest & Sander Mücher	Erik Meesters[1]
7	Tourism	Diana Slijkerman, René Henkens	Matthijs van der Geest
8	Remote sensing tools	Sander Mücher, Nafiseh Ghasemi [2], Henk kramer[2], Wouter Meijninger[2], Bert Lotz[5]	Bert Lotz

1: Wageningen Marine Research; 2: Wageningen Environmental Research; 3: Wageningen Economic Research; 4: Wageningen Bioprocess Engineering; 5: Wageningen Plant Research

Table 2 Stakeholders consulted in workshops and field visits

Organisation	type	Persons	NEXUS domain
Stinapa	NGO	Wijnand de Wolf, Leonell Martijn, Sabine Engel, Paolo Bertoul, Caren Eckrich	Ecosystem
Nature 2	Consultant	Kally de Meyer	Ecosystem
OLB	Government	Frank van Slobbe, Dianne Boelmans	Ecosystem, Water Energy, Food
WEB	Water and energy company	Hans Staring, Arthur Janga	Energy Water
RCN	Government	Paul Hoetjes, Yoeri de Vries	Ecosystem, Water, Energy, Food
LNV	Government/policymakers	Hayo Haanstra	Ecosystem Food
Chamber of commerce	Government	Gianni Marie van den Heuvel, Dick Ter Burg	Tourism
TNO	Research	Kris Kats	Ecosystem Energy
Boneiru Duraderu	Local small scale initiative/sustainable project coordination	Sharon Bol	Ecosystem Water Energy, Food
Zilte landbouw Texel	Entrepreneur	Marc van Rijsselberge	Water Food
Wageningen UR Livestock Research	Research	Francesca Neijenhuis	Ecosystem Food
Wayaká Advies	Consultancy	Jan Jaap van Almenkerk	Water Food

To conclude

As summarized below, our work clearly elucidates the benefits of using an integrated Nexus approach to improve water, food, energy and ecosystems security on small tropical islands like Bonaire. Overall, maintaining and restoring ecosystem services are key in the Water-Food- Energy-Ecosystem Nexus for small tropical islands. Sustainable development of these domains, and integration between them, such as provisioned within a nexus approach, requires ecosystem-based management founded on shared fact finding, for which long term monitoring of values (ecological and socio-economical) should be the basis. Leadership, capacity, strategy and allocation of budget are key factors that should be dealt with in a more optimal and integrated (nexus) way. In factsheets 1-8 more detailed information is provided.

Water (more details in factsheets 1, 2, 4, 5, 6, 7): The reuse of treated waste water provides opportunities for more optimal use of treated waste water in other nexus domains, including agriculture, aquaculture and hydroculture and nature creation. However, each destination requires certain quantity and quality aspects, including logistics. The varying quality requirements, need to be defined in a larger stakeholder settings, so that win-win situations can be identified and planned for. In addition, the surplus of produced water by the predicted increase of tourist numbers in the future creates opportunities to re-allocate the increasing amount of waste water. Investments in monitoring of catchment specific characteristics (i.e. run off, vegetation cover, land use) will aid selection of key catchment areas for interventions to increase water retention and prevent erosion, which will contribute and integrate other nexus domains by increasing crop yields and reducing impact on adjacent coastal habitats. Moreover, investments in the production of more renewable energy would lower the price of water.

Food (more details in factsheets 1, 2, 3, 4, 6): The aim is a sustainable and resilient production of affordable, healthy, safe food, at a scale that is sufficient to feed all people. The main challenges are lack of (suitable) water for irrigation of crops and the current practice of extensive unmanaged goat husbandry that leads to deforestation, desertification and disruption of the hydrological cycles through overgrazing-induced erosion by free-roaming goats. To increase yield from goat husbandry and reduce its ecological impact, goats should be kept behind fences, and fed with locally produced high-quality fodder. To substantially increase local food production, the Nexus intervention would be to focus investments in both the development of constructions to collect, re-direct and store (rain)-water for irrigation. Investments are also needed in the re-allocation of treated water towards agricultural activities such as horticulture, hydroponics, and production of fodder. A multi stakeholder approach is needed to communicate quality criteria and logistics In addition setting up courses where (young) people receive education about agriculture and nature, but also to interest young people in growing food, would probably empower the sector.

Food from the ocean promises to stimulate food provisioning without compromising other dimensions of the water-energy-food-ecosystem NEXUS, and it can benefit from innovative developments such as OTEC or algae parcs to build a business case within aquaculture by reducing energy and water use. The application of fishing attracting devices (FADs) may lower the current impact on coastal ecosystems (and thus increases ecosystem resilience), however, only when done in accordance to sustainable fisheries principles.

Energy (more details in factsheets 1, 2, 5): Aim is to achieve affordable, safe, reliable and 100% renewable energy supply, integrated with other resource sectors to reduce trade-offs and provide synergies between water-food-energy-ecosystem domains. The challenge is to cope with the current quality and to extent the capacity of the electricity network which currently limits expansion of wind/solar energy generation, resulting in a shortage in production capacity. Intervention would be to develop and implement a Sustainable Energy vision that integrates the Food, Water and Ecosystems domains to simultaneously aid energy, water, food and ecosystem security. Feasibility studies in Ocean Thermal Energy Conversion (OTEC) that integrates electricity generation with cooling, fresh water production, microalgae production and processing (biodiesel, feed, fertilizer) and aquaculture should be executed to simultaneously aid energy , water, food and ecosystem security.

Ecosystems (more details in factsheets 1- 8): The challenge is to reduce global climate change effects through local measures aiming at increasing resilience by reducing human pressures (pollution, disturbance, exploitation). Implementation of ecosystem-based management across all sectors helps to maintain ecosystem services. Intervention should focus on changing human behaviour by creating awareness about the services ecosystems provide for humans and by providing alternative resource use options. The upscaling of current pilot projects targeting reduction of erosion & eutrophication caused by goats, and the introduction of Building with Nature/Nature inclusive concepts add to the Nexus approach, and would aid in the provisioning of many ecosystem services, including food, income from tourism and coastal protection.

Tools (factsheet 8): To support the NEXUS approach evidence based monitoring tools are of large contribution that can provide policy makers, conservation managers, entrepeneurs, scientists and the general public with information on the state, pressures and associated changes in the environment. Remotely sensed information can help to provide information on e.g. land cover and associated dynamics such as urban sprawl, mapping habitats such as mangroves and coral reefs, surveying terrain conditions such as soil moisture conditions and erosion hazards associated within catchments, sea level rise and changing coastlines, and on many aspects of the vegetation (natural and agriculture). Remotely sensed information can in general make field surveys and monitoring more effective, and can thoroughly support decision making.

Project details

Projectnumbers: 4318300087/ 4318300089/ 4318300090/ 4318300091

Project leader: Diana Slijkerman
Team members: Dr. Matthijs van der Geest Dr. Sander Mücher, Dr. Dolfi Debrot, Dr. Sander van der Burg, Dr. Iago Dominguez Teles, Dr. Rene Henkens, dr. Nafiseh Ghasemi, dr.Henk Kramer, Wouter Meijninger, dr. Bert Lotz

This letter report is reviewed by a colleague, and a member of the management team of Wageningen Marine Research.

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Nexus interventions for small tropical islands: case study Bonaire

Introduction

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Following global trends in population growth, urbanization and rising living standards, the global demand for water, food and energy is rapidly increasing. Meeting this surge of demand poses heavy pressures on existing water, food and energy systems. Typically these have already been constrained due to the competing needs for limited resources in many parts of the world and growing climate change effects. These challenges are even more pronounced for Small Island Developing States (SIDS), due their small size, high population density, remoteness from centres of production, and vulnerability to environmental and exogenous economic influences. Nevertheless, achieving access to affordable, reliable and sustainable water, food and energy within the island boundaries is often possible. This requires a holistic "Nexus approach" that considers the inter-connections between water, food, and energy sectors in relation to the ecosystems on which these sectors depend. In this context it is vital to seek interdisciplinary solutions to scarcity of resources that allow mutually beneficial responses and synergies between sectors that promote efficiency while at the same time they reduce ecological degradation. Using the Caribbean island of Bonaire as a case study, we explore how this "NEXUS approach" can aid resource and ecosystem security in SIDS.

AN INTERLINKED WORLD

Water, food, and energy security are fundamental to modern society. Global trends in population growth, urbanization and rising living standards, are intensifying the demand for these resources which is estimated to increase by more than 50% by 2050, in comparison to 2015 levels (Ferroukhi et al., 2015). Meeting this surge of resource demand poses a huge pressure on existing water, food and energy systems, and the ecosystem on which these systems depend. Adding to this is the growing threat of climate change, which will have huge impacts on ecosystem functioning and related resource availability. Given this tremendous world-wide challenge, it is increasingly clear that in an interlinked world, there is no place for conventional planning and decision making that focusses on single sector approaches. After all, increased pressure on one of the resource sectors often has negative consequences for one or more of the other sectors, due to the presence of trade-offs and feedback loops. The production of agro-fuels, for example, requires water and occupies land that could be used to grow food or to support the natural environment and ecosystem services. Large-scale dependence on groundwater pumping for irrigation often leads to increased pumping in case of drought, and subsequent increased electricity demand. When this coincides with water shortages for cooling power plants and hydropower generation, this can interfere with power production and lead to power outages potentially affecting the whole population. Thus, increasing evidence suggests that international goals such as the ambitious Sustainable Development Goals (SDGs) and the Paris climate agreement can only be achieved with an integrated, multidisciplinary (beta- and gamma) and interdisciplinary NEXUS approach.

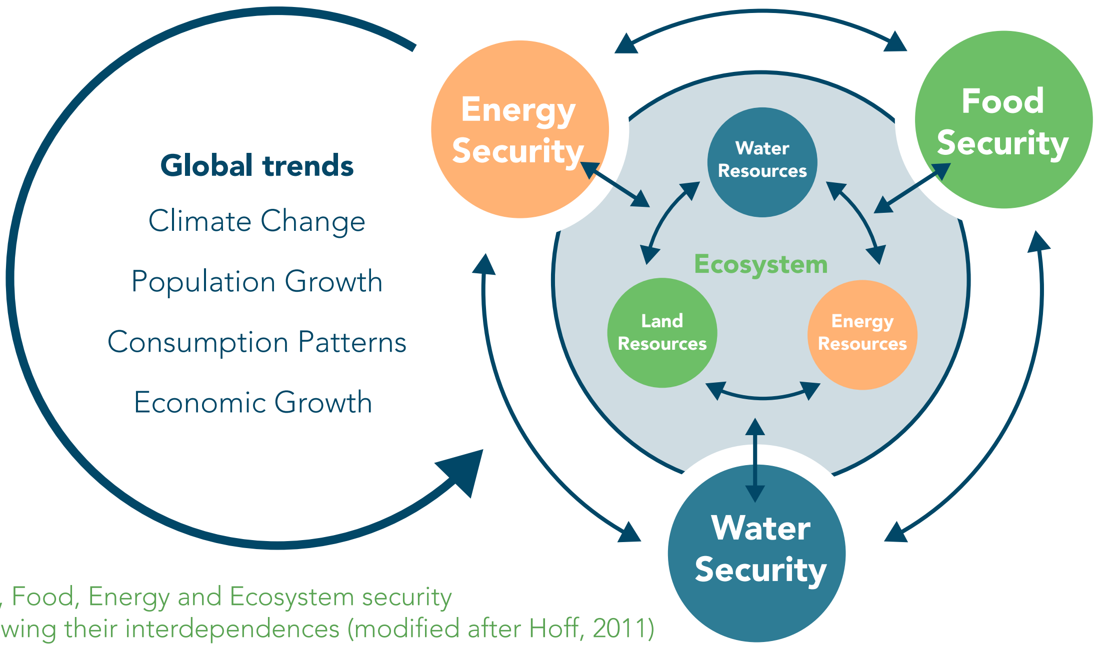

Figure 1.
The Water, Food, Energy and Ecosystem security Nexus showing their interdependences (modified after Hoff, 2011)

In recent years, the **Water-Food-Energy-Ecosystem (WFEE)** Nexus has emerged as a powerful concept to capture these interdependencies between ecosystems and the water, food, and energy sectors (see Fig. 1), and is now a key tool for policy-making. This Nexus approach helps to define trade-offs between resource sectors and the environment and helps build synergies across these sectors and the environment to increase resource use efficiency. In comparison to existing independent sectoral approaches to the management of water, food, energy and ecosystems, this Nexus approach thus helps to reduce costs and increase benefits for both society and environment. However, there is concern that the Nexus approach represents primarily a framing of issues and a call for action with limited practical value (Leck et al 2015).

Small Islands Developing States: the ideal candidate for the Nexus approach

Small Island Developing States (SIDS) comprise 52 countries and territories, that are home to more than 50 million people, 43 of them located in the Caribbean and the Pacific regions (Boto & Biasca 2012). The natural, economic and social systems of SIDS are considered highly vulnerable, due to the intrinsic characteristics of SIDS, including: small size; relatively high population density, remoteness; vulnerability to external (demand and supply-side) effects; narrow resource base; and exposure to global environmental challenges such as sea level rise (Briguglio, 1995). With their fragile ecosystems, SIDS are also highly vulnerable to domestic pollution factors (Boto & Biasca 2012).

These challenges were highlighted in the 1994 Barbados Programme of Action (BPOA) and the Mauritius Strategy of Implementation (MSI) of 2005, both of which stated that the difficulties SIDS face in the pursuit of sustainable development are particularly severe.

SIDS are thus a potential model for the future, facing now what must become the long-term preoccupation of the whole world as resource degradation approaches the limits of the planet. Given the tremendous challenges SIDS face, applying the nexus approach to SIDS may be particularly beneficial in embedding and achieving sustainability. Moreover, the reduced complexity typical for small and isolated tropical islands states, offers an unique opportunity to identify nexus challenges, and possible solutions that can be effectively implemented and monitored. As such, implementation of the nexus approach on SIDS, can contribute to the urgently needed proof of the practical value of the Nexus approach.

Typical negative feedback loops for SIDS

The challenges that SIDS face are varied, but all conspire to constrain their development processes. SIDS typically do not have a wide base of resources available to them, and thus do not benefit from cost advantages that this could potentially generate. Coupled with small domestic markets, they experience difficulties in profiting from globalisation and trade liberalisation and are reliant on external and remote markets with limited opportunities for the local private sectors. The costs of the provision of energy, infrastructure, transport and communication are also often high, and along with typically high population densities, create increased pressure on these already limited markets. (UNEP 2014, Dodds & Bartram 2016)

In addition, SIDS typically have a heavy reliance on unsustainable tourism, which enhances coastal deterioration through increased coastal erosion, pollution and disturbance, eventually leading to loss of coastal ecosystem services (Fig. 2). As a result, SIDS gradually become less attractive as a tourist destination. This will tend to lower the number of visiting tourists, and reduce the financial income of tourist operators, which again drives unsustainable tourism practices.

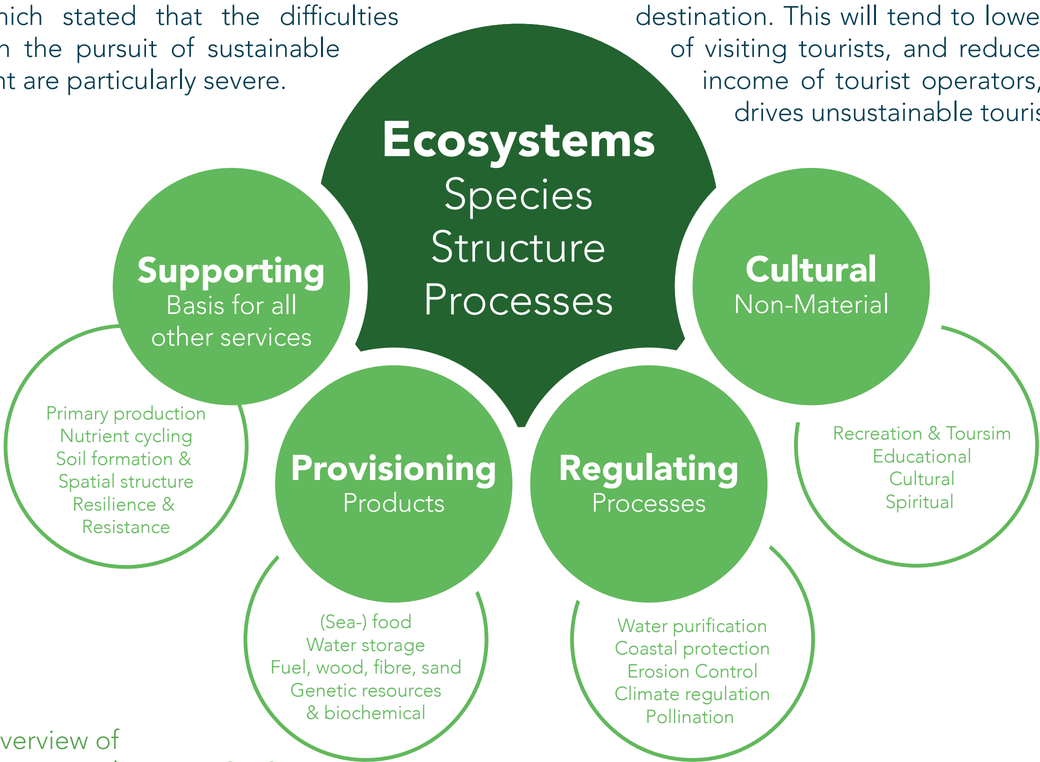

Figure 2. Overview of ecosystem services relevant to SIDS

Moreover, as most SIDS are located in tropical and sub-tropical oceans, their climate is strongly influenced by large-scale ocean-atmosphere interactions. These often manifest themselves in extreme weather events such as hurricanes and cyclones. Such phenomena are associated with storm surges, coral bleaching, inundation of land, and erosion, incurring high costs of damage to socio-economic and cultural infrastructure (Sem, 2007). Due to fears of a recurrence of similar natural disasters, investors can become hesitant, which holds back economic development, leading to increased poverty, which eventually will make the local community less resilient to deal with any subsequent natural disaster.

The WFEE Nexus approach as intervention for SIDS

We suggest that SIDS must shift from resource-wasteful technologies and practices to integrate the Nexus approach in policy planning and programming, in order to maximize resources and opportunities for efficiencies, cost effectiveness and sustainable growth. Strategies will need to include proper appraisal of natural capital, utilizing renewable energy resources and using size and scalability in SIDS as an advantage for the creation of new models of green development and sustainability. As such, regional approaches should be deployed to create economies of scale, based on the development of agricultural systems which have low energy and water demands, and which fit within the context of the environmental limits and possibilities.

At the core of the 'Nexus approach' is the recognition that water, energy, food and other resources are limited and that they are interlinked in a complex web of relations linking resource use and availability (Hoff 2011). Based on existing literature (Boto & Biasca 2012, UNEP 2014, Dodds & Bartram 2016), we identified the main Nexus interlinkages for SIDS which are presented in Box 1. below.

Box 1. Overview of main Nexus interlinkages between Water, Food, Energy and Ecosystems that are relevant to SIDS

Nexus interlinkages	Water	Food	Energy	Ecosystem
Water	Water stressed. Relatively small watersheds, limited precipitation constrained to wet season only, high evaporation. Water mainly produced out of seawater, which is a costly process resulting in water being relatively expensive	Irrigation of food/feed crops, drinking water for livestock, food production and processing, production of fertilizers. Amount of water stored in reservoirs, its management and the price of water determines yield production and price.	Water reservoirs can be used for hydropower generation, power plant cooling, drilling/ mining and refining fuels, fuel transportation in pipelines, Ocean Thermal Energy Conversion (OTEC)	Habitat loss due to water run-off and subsequent eutrophication and sedimentation of water bodies and coastal zones, changes in the ability to support biota and biological communities, due to changes in availability and quality of water
Food	Choice of crops, irrigation systems, and expansion of irrigated areas determine the demand of water for irrigation. Crops can create microclimate (shadow, less evaporation, rooted zone storing water in sediment) and as such increase groundwater volume, while crops can also reduce erosion-related water run off	Excessive dependence on imported food and hence vulnerable to global developments. Heavy dependence on coastal and marine resource for food security	Production of first generation biofuels by combustion of food waste	Habitat degradation, fragmentation and destruction due to expansion of agriculture, fisheries and aquaculture. Pressure on available water and land for nature. Soil degradation (erosion, compaction), sediment run-off and sedimentation, pollution from pesticides, fertilizers, manure, antibiotics etc., declining population sizes of wildlife, reduced biodiversity and ecosystem resilience
Energy	Energy demand in water pumping, production and distribution of drinking water, waste water treatment	Use of energy for food production, processing and transport. Prices relatively high due to dependency on import of fossil fuel	90% imported fossil fuels; vulnerable to oil price fluctuations	Habitat loss due to deployment of power plants and fuel extraction, soil and water pollution from fuel extraction, oil spills, pipeline leaks etc.. Air pollution from fuel combustion
Ecosystem	Provides ecosystem services such as water purification, recycling of nutrients, water flow regulation, energy buffer and erosion prevention, reduced evaporation of water by vegetation, storage of water by vegetation.	Biophysical support for crop and livestock production, fisheries and of aquaculture. (Micro-) climate regulation, pest management, support for pollination of crops by wildlife (i.e. insects, birds, bats)	Biophysical support for biofuel crop and biomass production. Ecosystem service of carbon sequestration (mitigating waste from energy sector)	The tendency to have high degrees of endemism and levels of biodiversity, but the relatively small numbers of the various species impose high risks of extinction and create a need for protection

Bonaire case study

Our case study focuses on Bonaire as a "demonstration" island for the nexus approach. Bonaire is a southern Caribbean island and part of the Dutch Kingdom and exemplifies many other small tropical islands in the Caribbean and elsewhere. Bonaire is not officially defined as a SIDS by the UN, but has features that do apply to the concept such as small but growing populations, limited resources, remoteness, susceptibility to natural disasters, excessive dependence on international trade, and fragile environments. It was recognized by commission Spies (Spies 2015), that the economy of Bonaire is small-scale and vulnerable because of the dependence on a limited number of sectors (Box 2). The conclusion was that to be more self-supporting and to be able to cope with future challenges, several interventions are needed. It is not only important to preserve and strengthen existing sectors, but also to exploit opportunities for diversification of sectors (Spies, 2015).

Bonaire is currently being confronted with an increasing population via immigration and increasing numbers of tourists visiting the island. Moreover, it is totally dependent on the import of food, the production of water and electricity from fossil fuels, which all result in high costs. Since the recent socio-economic turmoil in Venezuela, cheap import of fruits and vegetables has proven undependable. Furthermore, inhabitants rate life quality on the island as poor, whereby the combination of dietary habits and cost of living worsen health problems (Spies, 2015).

As is the case for many other tropical islands, the tourist economy of Bonaire is vulnerable, depending mainly on its limited and vulnerable natural marine resources. Tourism-related coastal development puts pressures on ecosystem resilience through habitat loss, waste production, and water and energy use, enhancing feedback loops with negative consequences in the nexus.

The island's agriculture is currently insufficient to secure food supply (99% of the food consumed is imported), while water supply is dependent on the desalinisation of seawater, which is a very energy consuming and thus costly process. The current practice of extensive unmanaged animal husbandry leads to overgrazing, deforestation and disruption of the hydrological cycles. This in turn leads to loss of topsoil (erosion), reduced groundwater replenishment, desertification, extinction of plant species and the loss of biodiversity. The runoff of sediments and nutrients due to overgrazing and coastal development have contributed to severe deterioration of the island's fringing coral reefs and mangrove habitats, which are the main attraction for the tourism industry and crucial to the island's economy. To make matters worse, climate change presents exacerbating challenges to Bonaire because of its small geographical area and generally low altitude. The associated challenges from sea-level rise, altered rainfall patterns, and storm-surges form major threats to long-term sustainable development.

Box 2. Socio-economical background information about Bonaire (CBS, 2018)

Size	288 km2
Population size	19500 (2018) – increase of 25 % since 2010 (migration main factor)
Population density	68/km2
Disposable income (mean)	24.1 thousand USD/household
Unemployment rate	6.9
Trade deficit	202 million USD
gross domestic product (GDP)	434 million US dollars (2016), tourism accounts for 16.4 % (2012)
GDP/capita	was 22,500 USD (2016)
Consumer price index	>103 (compared to 2011)

Governance and policy framework Bonaire

The relevant policy and governance framework for Bonaire is complex. International, regional, local en Dutch policies apply. In this factsheet these are not discussed in detail. In short, Bonaire, are Dutch overseas 'public entities'. Responsibilities and authority are divided between the Island Government themselves and the National Government by means of the National Office for the Caribbean Netherlands (Rijksdienst Caribisch Nederland). The Caribbean Netherlands of which Bonaire forms part, largely has its own laws and regulations, called BES-laws. Nature and fisheries regulations have largely been taken over from the former Netherlands Antilles. Various International Treaties and Conventions to which the Kingdom of the Netherlands is a signatory party also apply to Bonaire. Many obligations under international agreements have been incorporated into national legislation applying to these Dutch overseas entities. The Dutch National Government and the (local) island government are primarily responsible for (nature) policy and its implementation. Additionally, several government commissions and many non-governmental parties are also active in management implementation at various levels. Joint, multisectoral goal setting and proper coordination and cooperation are the key to success in all sectors.

Key stakeholders (not complete)

- The people of Bonaire
- RCN
- OLB
- LVV
- Dutch ministry of EZ and IenW
- STINAPA
- TCB (Tourism Corporation Bonaire)
- BONHATA (Bonaire Hotel and Tourism Association)
- SELIBON (Servico di Limpiesa, Boneiru)
- WEB
- Cargill
- PISKABON
- Local NGO's and SME's

The Spies Committee (2015) noted that given the small scale of Bonaire and the limited available capacity it is difficult to sustainably guarantee the quality of management and the associated official organization. The situation is too dependent on the effort and quality of individual people. As a result, the administrative power can vary considerably between successive Executive Councils (Spies, 2015). Moreover, governmental instability due to rapid changes of executive councils does not contribute to the continuity needed for structural follow-up of decisions, effective implementation and results for society (Spies, 2015). An observed common thread in the discussions in the various organizations was the lack of shared island vision and guidance, which often are the root cause for the absence and / or the delayed implementation of decisions and policy within these organizations. Given organisational malfunctioning at some governmental departments, The Netherlands appointed a so called "Bestuurs akkoord", in which agreements were reached for additional funds and investments. Allocated funds formed part of the so-called "regio envelop", directed towards setting up and strengthening primary sector projects in order to improve local food production.

Key international policies relevant for Bonaire

At international level

- UN sustainable development 2030 agenda (SDG's), in particular goals number 1, 6, 7, 8, 9, 11, 12, 13, 14, 15, 17 (in context of the nexus)
- RAMSAR Convention on wetlands
- Convention on Biological Diversity (CBD)
- the Bonn Convention (or the Convention on Migratory Species of Wild Animals (CMS)
- CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora)

At regional level

- Inter-American Convention for the Protection and Conservation of Sea Turtles (IAC).
- Cartagena Convention (for the Protection and Development of the Marine Environment of the Wider Caribbean Region with the SPAW Protocol (concerning Specially Protected Areas and Wildlife)

At local level

- Nature Conservation Framework Act BES [Wet grondslagen natuurbeheer en -bescherming BES].
- The Fisheries Act BES [Visserijwet BES] and the Maritime Management Act BES [Wet Maritiem Beheer BES]
- Public Housing, Spatial Planning and Environmental Protection Act BES [Wet VROM BES]
- Various regulations aimed at water, energy, nature, marine park, waste etc.

Factsheets

In the following part of this document, a series of factsheets will be presented to summarise various Nexus interventions on Bonaire (see Box 3). In these sheets, current and desired state is described, including the challenges, and possible nexus solutions. Special notes on governance issues are made.

Input for the various fact sheets was obtained based on a review of prior literature and the results of workshops and meetings (held between 14-10-2018 and 19-10-2018) with various organisations on island (see Box 4).

Box 3. Overview of factsheets per Nexus domain

1	Introduction	Matthijs van der Geest[1] & Diana Slijkerman[1]	Dolfi Debrot[1]
2	Water	Diana Slijkerman[1], Matthijs van der Geest[1] & Sander Mücher[2]	Dolfi Debrot[1]
3	Food from the ocean	Dolfi Debrot[1] & Sander van der Brug[3]	Diana Slijkerman[1] & Martin de Graaf[1]
4	Food from the land	Matthijs van der Geest[1] & Diana Slijkerman[1]	Dolfi Debrot[1]
5	Energy	Matthijs van der Geest[1] & Iago Teles[4]	Diana Slijkerman[1]
6	Ecosystems	Diana Slijkerman[1], Dolfi Debrot[1], René Henkens[2], Matthijs van der Geest[1] & Sander Mücher[2]	Erik Meesters[1]
7	Tourism	Diana Slijkerman[1] & René Henkens[2]	Matthijs van der Geest[1]
8	Remote sensing tools	Sander Mücher[2], Nafiseh Ghasemi[2], Henk kramer[2], Wouter Meijninger[2] & Bert Lotz[5]	Bert Lotz[5]

1: Wageningen Marine Research, 2: Wageningen Environmental Research, 3: Wageningen Economic Research, 4: Wageningen Bioprocess Engineering, 5: Wageningen Plant Research

Box 4. Organizations that were consulted for input for the various factsheets presented in this document

Organisation	Type	Persons	NEXUS domain
Stinapa	NGO	Wijnand de Wolf, Leonell Martijn, Sabine Engel, Paolo Bertoul, Caren Eckrich	Ecosystem
Nature 2	Consultant	Kally de Meyer	Ecosystem
OLB	Government	Frank van Slobbe, Dianne Boelmans	Ecosystem, Water, Energy, Food
WEB	Water and energy company	Hans Staring, Arthur Janga	Energy, Water
RCN	Government	Paul Hoetjes, Yoeri de Vries	Ecosystem, Water, Energy, Food
LNV	Government/policymakers	Hayo Haanstra	Ecosystem, Food
Chamber of Commerce	Government	Gianni Marie van den Heuvel, Dick Ter Burg	Tourism
TNO	Research	Kris Kats	Ecosystem, Energy
Boneiru Duraderu	Local small scale initiative/ sustainable project coordination	Sharon Bol	Ecosystem, Water, Energy, Food
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Wageningen UR Livestock Research	Research	Francesca Neijenhuis	Ecosystem, Food
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Colophon

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WAGENINGEN UNIVERSITY & RESEARCH

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We thank all persons and organisations mentioned in Box 4 for their contributions and sharing of information during meetings, workshops, and field visits.

The KB program “Nexus Strategic policy case”, included a Bonaire NEXUS case study. The case study was funded under KB-33-005-013, and administered under project number 4318300087. A letter report (number 1900369.ds) summarises the activities. In the study a set of 8 factsheets was drafted (and attached to the letter report). The set of factsheets can be found on : www.wur.eu/sustainablewatermanagement
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Nexus interventions for small tropical islands: case study Bonaire

Water

Diana Slijkerman, Matthijs van der Geest & Dolfi Debrot

WAGENINGEN UNIVERSITY & RESEARCH

Water is a scarce natural resource on most small tropical islands, including Bonaire. Factors as 'when', 'where' and 'what kind of water' (in terms of quality) all steer water availability, and often results in a mismatch between water supply and water demand. The loss of water due to evaporation and run off is generally large, with the latter causing severe impacts on coastal ecosystems (e.g. mangroves, seagrass beds, coral reefs) through enhanced coastal eutrophication and sedimentation.

To meet the island demand, drinking water is generally produced from seawater via reverse osmosis, an energy-demanding process, that drives the price of water. Recycling of drinking water is therefore profitable, and as a result treated waste water is a valuable source of water on Bonaire. Current destinations for treated waste water are irrigation of gardens and crops, power plant cooling and the allocation into a wetland/pond. Application of the Nexus approach shows that necessities and prioritization of treated waste water provides opportunities for additional destinations of treated waste water, including agriculture, aquaculture and hydroculture. However, these alternative destinations involve certain quantity and quality requirements related to the treated 'grey' water. The varying requirements need to be discussed in a larger stakeholder settings, so that win-win situations can be identified and planned for. Additional nexus interventions include reducing the degradation and loss of freshwater resources through technical and ecological (Building with Nature) measures, rainwater harvesting (which limits run off related impact on coastal ecosystems), water reuse/recycling, increasing the use of renewable energy for desalinisation, low-cost wastewater treatment facilities such as artificial wetlands, increasing awareness on water conservation, and integrated water and land management.

	Current state	Desired state	Challenge	Nexus intervention
Rainfall & Groundwater	Limited supply, but integrated water management plan is lacking Low ability of soil to retain rainfall Water run off to coastal zone. Causes flooding of urban areas, and enhances erosion with severe impact on coastal habitats Ongoing salinization of groundwater due to sea level rise Groundwater is brackish, limiting its use Climate change effect on rainfall patterns and water	Retention of rain water to groundwater Improved quality of groundwater No/less water run off to coastal zone Surface retention and direct use of rainwater Shared fact finding	Rainfall is mostly restricted to the wet season Unknown groundwater balance and quality in time and space Unknown where to apply interventions to retain water and lower impact of run off on coastal habitats	Create awareness among stakeholders for the necessity to develop an integrated water management plan Set-up a programme to monitor groundwater level and quality to allow knowledge-based interventions Identify catchment areas and catchment specific characteristics (i.e. run off, vegetation cover, land use) to select key catchment areas for interventions to increase water retention/reduce run off
Drinking Water	High price due to use of imported fossil fuels for production Increased demand due to population growth/increasing living standards Unsustainable use (e.g. irrigation of gardens) Loss of drinking water during transportation to end user due to leaking pipelines	Affordable water Reduced demand Sustainable use Reduced loss	Decrease price of production Difficult to change consumption patterns	Use renewable energy to lower price Use educational programmes to raise awareness on necessity and benefits of water conservation Improve water transportation infrastructure
Grey Water	Used in irrigation (50%), other 50% in pond Treatment up to high standards resulting in nutrient-poor treated waste Infrastructure for transportation lacking	100% used for irrigation or other smart destinations Quality in line with destination	Infrastructure is missing to allocate grey water to places of use Stakeholder discussion on quality requirements	Evaluate most effective destination of grey water via multi stakeholder meetings based on quantity, quality and treatment steps needed

Box 1. Summary factsheet Nexus-Water

INTRODUCTION: CURRENT STATE, TRENDS & DRIVERS OF CHANGE

Water is critical to the survival of all living organisms. Yet, most small tropical island states, including Bonaire, are experiencing increasing shortage of fresh water as a result of multiple anthropogenic pressures (e.g. population growth, urbanization, rising living standards) and climate change impacts on their already vulnerable fresh water resources. Water scarcity has far-reaching impacts on sustainable development and could even jeopardize the continued human habitation of some islands.

Due to the lack of lakes and rivers on most small tropical islands, fresh water is typically derived from precipitation and/or groundwater storage. Fresh water is however not equal to potable water. The latter requires specific treatment steps before it becomes suitable for drinking. In the case of Bonaire, the following forms of water sources can be identified:

1) rainfall: stored in reservoirs and used for irrigation of crops and gardens
2) groundwater: used for irrigation of crops and consumption by cattle
3) drinking water: obtained from seawater via reverse osmosis and used for human consumption
4) grey water (from sewage treatment): used for irrigation of crops and gardens

Rainfall & groundwater

The partitioning of rainfall over surface runoff, infiltration and evaporation is determined by the amount of rainfall, wind conditions, temperature and the type of soil. The less rain, the more will evaporate before it is able to infiltrate in the soil and reach the aquifers. Soil, like the local "diabase" (weathered top layer of the volcanic formation) makes infiltration difficult, resulting in large run off via roois (seasonal streams). In the diabase terrain many dams and reservoirs (tankis) are constructed to retain rainwater. These reservoirs hold water during a few months after the rainy season. A large part of the stored water will evaporate, and depending on the local soil conditions, a part of the water will infiltrate into the soil or into the many cracks of the karstified limestones (Borst & De Haas, 2005), where it adds to the groundwater reservoir. On Bonaire, groundwater is generally brackish (electrical conductivity 2,000 to 4,000 µS/cm) and, apart from Fontein (a spring), there are no constant streams and springs (Borst and de Haas 2005). Across the island, large spatial differences in salinity levels of ground water exist. In figure 1 the geohydrological situation is schematized for the situation over Kralendijk and Fontein. Differences in soil composition results in different run off and infiltration patterns. The volcanic material acts as an impermeable base for the water flowing through the more permeable limestones. At the place where the volcanic material crops out again, such as at Fontein- at the east side- the water may come to the surface and forms a spring (Borst & De Haas, 2005). Water flowing sub-terraneously though limestone landscapes is accessed at many locations via manmade karst wells and natural karst caverns.

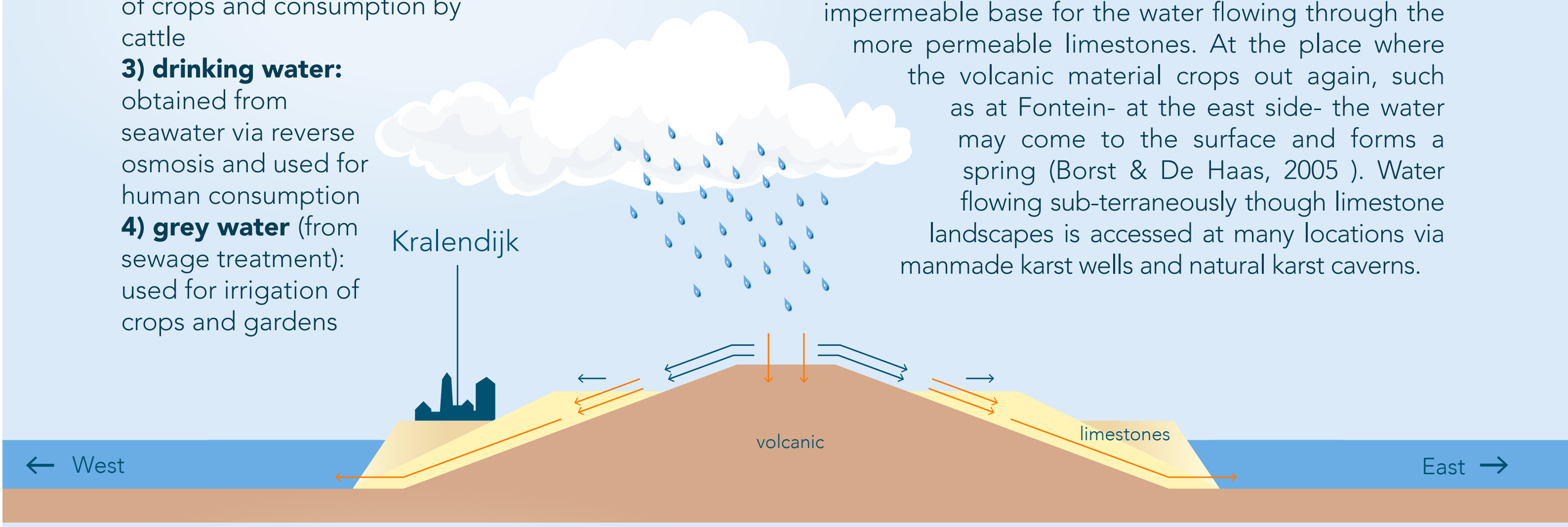
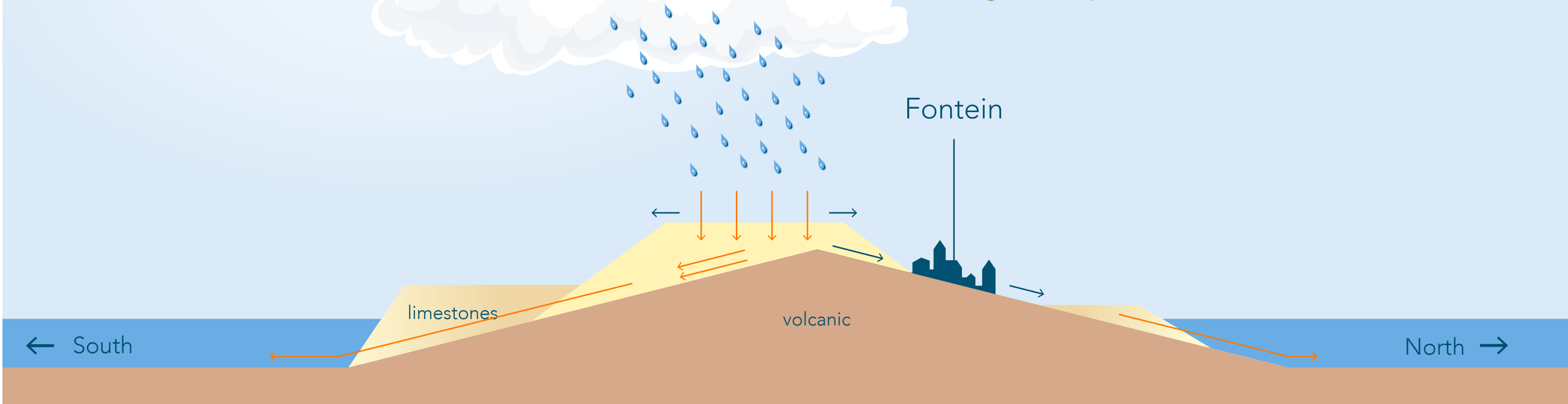


Figure 1. Above: Geohydrological situation in a schematic cross-section over Kralendijk.

Below: Geohydrological situation in a schematic cross-section over Fontein. Red arrows indicate infiltration, blue arrows indicate surface runoff.
Figures adapted from Borst & De Haas, 2005.



Rainwater is collected and only sometimes harvested in reservoirs during the rainy season which lasts from October to December. The water in these reservoirs becomes brackish, as a result of high evaporation rates. Local people use this water for irrigation of relatively salt tolerant crops like maize, for consumption by goats (Borst & De Haas, 2005) and occasionally for construction activities (pers. comm. Jan Jaap van Almenkerk). Salinity levels of the water provided by wells (Figure 4).

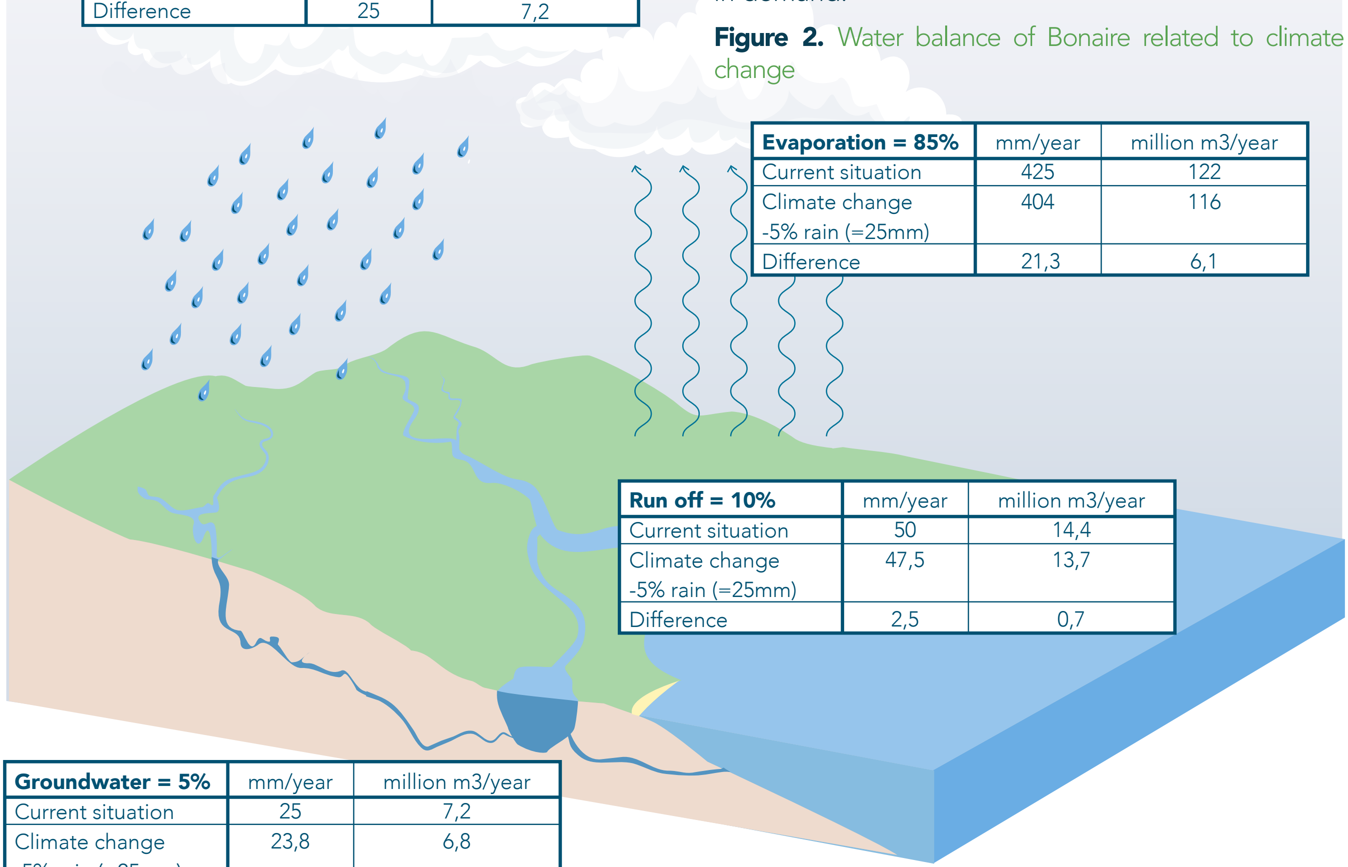
The recharge of ground water levels by rainwater infiltration will likely decrease due to climate change. ICCP predicts (intermediate low-emissions scenario), that the Caribbean Region by the end of this century will face a decrease in rainfall of 5 to 6% (ICCP, 2013). The current annual rainfall of ~500 mm (litre/m2) would then be ~475 mm. When extrapolated to the total surface of Bonaire (288 km2) this decrease of rainfall equals a decrease of an annual 7.200.000 m3 of rainwater. Based on previously documented evaporation rates for Bonaire and the expected percentage of rain water lost due to run off (Borst & De Haas, 2005), only 5% of this rainwater will recharge into the groundwater system (Figure 2). This results in a decreased water availability to the groundwater system of **360.000 m3 per year.** This will further decrease water availability for crop irrigation and animal husbandry, increasing the pressure on already limited water supplies. Moreover, a decrease of fresh water input to the ground water reservoir will increase the risk of salinization of groundwater. Deeper saline groundwater will be able to move upward to replace the space previously occupied by freshwater, salt water intrusion lead to even higher salinity levels of groundwater in the wells. Salinization of groundwater resources will also be exacerbated by predicted sea-level rise and the storage capacity of groundwater aquifers will be further reduced.

Drinking water

At present, the supply of drinking water for the approximate 20,000 inhabitants of Bonaire is produced from desalinated seawater via reversed osmosis and additional treatment steps, as managed by WEB Bonaire. This desalinisation treatment demands much energy, resulting in a relatively high price for water. The price of water is subsidised by the Dutch government in order to keep water affordable for the population.

In 2016, WEB produced 1,600 m^3 of drinking water, and partner GE Water & Process Technology added 4,000 m^3. For 2016, this brings the total production capacity on Bonaire at 5,600 m^3/day. The actual production is much lower, being only 4,800 m^3 of water production per day in 2018. Based on the history of construction activities and current construction requests, WEB predicts that daily water production and consumption will increase to 6,400 m^3 in 2024 and 8800 m^3 in 2030. Upscaling of the production is in line with this increase in demand.

Figure 2. Water balance of Bonaire related to climate change



Rainfall	mm/year	million m3/year
Current situation	500	144
Climate change -5% rain (=25mm)	475	136,8
Difference	25	7,2

Evaporation = 85%	mm/year	million m3/year
Current situation	425	122
Climate change -5% rain (=25mm)	404	116
Difference	21,3	6,1

Run off = 10%	mm/year	million m3/year
Current situation	50	14,4
Climate change -5% rain (=25mm)	47,5	13,7
Difference	2,5	0,7

Groundwater = 5%	mm/year	million m3/year
Current situation	25	7,2
Climate change -5% rain (=25mm)	23,8	6,8
Difference	1,3	0,36

Grey water

The first water treatment plant of Bonaire has been operational 2014, providing ~216,000 m^3 of treated waste water (grey water) per year. Increasing production is expected in the future due to population growth-related and increased in water use. Treated waste water is in potential a sustainable source of irrigation water. After taking some precautionary measures with regard to pollution, treated waste water can be used in agriculture. As treated waste water is relatively inexpensive compared to drinking water, it can be used to improve and scale-up water-demanding agricultural activities on the arid lands of Bonaire (see "Food from the land factsheet"), while simultaneously reducing the pressure on available fresh water resources.

Allocation of treated waste water

The initial plan was to allocate 75% of the treated waste water for irrigation of hotel gardens. However, due to technical problems with regard to the development of the necessary to transport the treated water from the treatment plant to the hotel gardens, the hotels have not been able to receive any treated waste water yet. As a result, hotels now use drinking water for irrigation of their gardens. Some hotels recycle their own untreated waste water for garden irrigation purposes. As all hotels have been built along the coast on porous limestone karst lands, this untreated grey water leaches rapidly into the adjacent coral reef habitat with many adverse effects for the nearshore coral communities.

Treated waste water is presently successfully being used for agricultural purposes (livestock fodder production and horticulture). Also in this case, logistic constraints to distribution are a major steering factor in the allocation of treated water. As a consequence, only 50% of the treated water is currently being used for irrigation of crops. A few fields (total 20 hectares) near the treatment plant, are irrigated directly with part of the available treated water (depending on the period up to 800 m^3/day), for fodder production for livestock, while a few trucks also transport water to nearby farmers. The remaining water is discharged into ditches near the water treatment plant, where it is slowly lost due to evaporation.

In 2021, the expected amount of usable effluent will have increased to 1400 m^3/day, due to increased consumption and thus increased waste water supply. Of this about 120 m^3 will be directed for vegetable crops, and 1280 m^3 for irrigation of 35 hectares for fodder production. However, getting the water to other areas where it can be used (such as the East Coast where a total of 25 hectares could be irrigated), but the necessary infrastructure is lacking (pipelines) and there is no solution yet in sight.

DESIRED FUTURE STATE

Rainwater and groundwater

Freshwater provisioning on Bonaire is still an unbalanced process, leading to crop damage or loss, and impacts on nature. Borst and De Haas already stated in 2005, that groundwater quality and quantity can be improved by retaining more rainwater (Borst and Haas, 2005) and this is still an aim today and for the future. In addition, an integrated water management plan should be implemented, which includes measures that prevent rainwater run-off to the coastal zone, and subsequent run-off related degradation of coastal habitats through sedimentation and eutrophication.

Drinking water

Affordable and accessible drinking water for everybody, that is produced, distributed and consumed in a sustainable way. Reverse-osmoses is an energy demanding process. In near future, a new seawater reverse-osmose (SWRO) installation will be installed, which will be a factor 1.6 more efficient in terms of energy use, because the water intake and pump system use less energy. The brine will be discharged at ~60 meters to reduce ecological impact on reef, instead of current situation where brine is discharged at surface. In nexus terms this new installation to produce water is a more sustainable solution: more efficient water production, with lower energy use, and in addition poses less impact on the environment (less CO^2 emission, less risks of oil spills, less brine in shallow coastal water). Lower energy use means lower costs, and cheaper product for the people who can spend the money on other things in their household (e.g food).

Grey water

All waste water from domestic use is recycled in a waste water treatment plant, so that treated waste water can be used for irrigation of food crops. Year-round availability of treated waste water will allow for year-round production of fodder for livestock and the irrigation of different types of salt resistant crops and the use of innovative techniques such as hydroponics, aquaponics and drip irrigation. Improved infrastructure related to the transport of treated waste water will allow irrigation of crops at multiple locations on Bonaire.

KNOWLEDGE NEEDS AND CHALLENGES

Rainfall and groundwater

Careful rainwater and groundwater management, including planning of land and water use, provide major environmental and socio-economic perspectives for sustainable development. The first step needed is an identification of the best potential water catchment and retention areas and most critical areas regarding impact (workshop outcomes, and Borst & De Haas, 2005, Roberts et al., 2017). Furthermore, the annual rainfall (144 million m^3/year) could in theory supply for the drinking water needs of the population. Question could be how to retain this water.

More detailed research, including the monitoring of groundwater levels and quality over a longer period would provide a better understanding of the groundwater system and run-off. Remote sensing techniques, together with run-off modelling (figure 3), presented in geographical information system (GIS) can assist both governmental organizations and future research projects, by identifying catchment areas for the most effective placement of dams. Since 2005, techniques for remote sensing have improved, and can be very useful for landscape management.

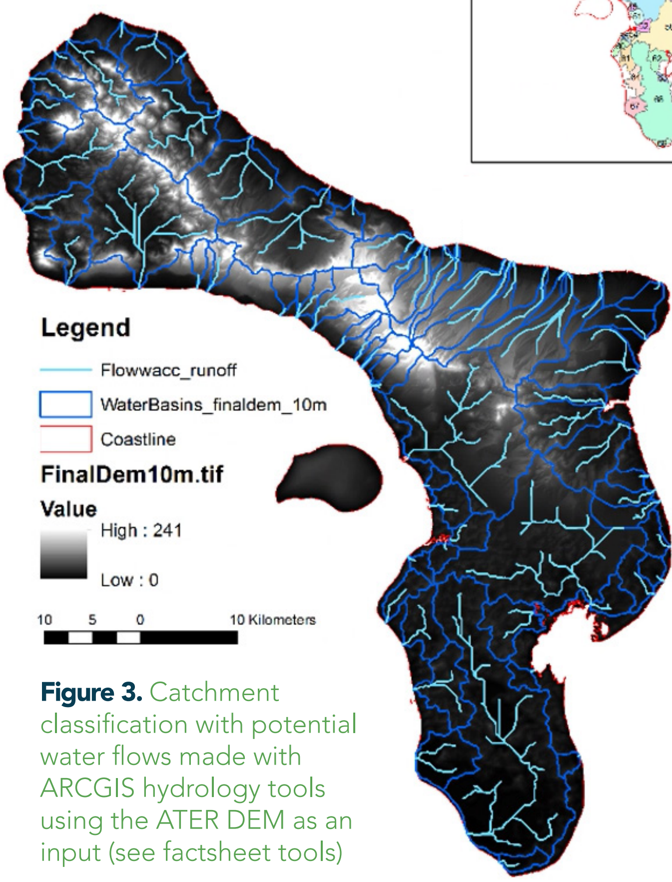


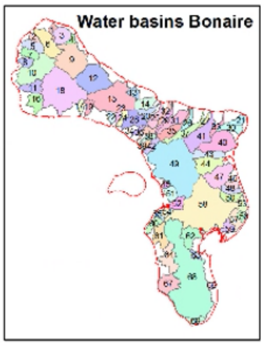
Figure 3. Catchment classification with potential water flows made with ARCGIS hydrology tools using the ATER DEM as an input (see factsheet tools)

Drinking water

Regarding security of drinking water on Bonaire, future challenges lay in lowering the costs related to the production of drinking water out of seawater, while additionally lowering human consumption through awareness raising campaigns on water use efficiency, pollution prevention and best agricultural practices.

Grey water

Quantity and quality issues for various end users asks for an assessment of needs and supply criteria. Currently, there is no infrastructure to transport treated waste water to end users like hotels near the coast and farms in rural areas. In light of the calcareous structure of the soil on Bonaire in combination with the high number of different land owners, construction of a pipeline infrastructure to transport treated waste water across Bonaire will be both expensive and difficult to implement. It will most likely require corporation of land owners. Optional above ground installation of pipelines could be an alternative.



During the process of waste water treatment, nutrients like nitrogen and phosphorus are removed from the water. This is good for water reused near the coast for hotel garden irrigation as it will reduce nutrient leaching into the coastal coral reefs. However, nutrient removal due to treatment is not an advantage when this is used for agricultural crop irrigation at inland farms as the nutrients can there be put to good use for crop production and will reduce the need for imported fertilizers.

Future grey water demand may also increase by allocation of grey water to ponds/wetlands systems to provide wildlife with a year-round accessible freshwater source, or for its use in aquaculture. Questions on water quality in relation to nature development or food production are foreseen. Effluent can contain a variety of contaminants that can accumulate in soils, crops or even the food chain and impact biological processes. Proper understanding of the water characteristics is needed to help allocating the water for suitable purposes.

Potential limitations of the treatment plant, and to meet quality requirements that depends on the increased volumes to process are not included in this study but should be looked into.

POSSIBLE NEXUS INTERVENTIONS

In this section interventions are presented to improve freshwater availability and use on Bonaire. Note that each suggested intervention assumes that water production and use should be compliant with human health criteria and environmental policy criteria.

Groundwater

Improved retention of rainwater can be achieved by restoring building and maintaining dams. Using modern remote-sensing technologies, catchment areas and their specific characteristics in terms of water run-off, vegetation cover, and soil moisture content, should be quantified, to provide policy makers with the knowledge on which measures are suitable for each specific catchment area. Water retention and prevention of run-off prevention can also be improved by increasing the vegetation cover. This could be achieved by revegetation programmes or by reducing the grazing pressure by free roaming livestock.

Improved retention and effective distribution and use of rainwater will result in:

- Reduced loss of fertile top soil due to run-off of rainwater
- Reduced risk of economic damage caused by flooding of urban areas
- Decreased impact of sedimentation on coastal habitats (e.g. mangroves, seagrass beds, coral reefs)
- Increased agricultural production

Drinking water

The price of drinking water on Bonaire is highly dependent on the price and the amount of energy needed to produce and transport drinking water. Currently, ~60% of the energy supply on Bonaire comes from burning fossil fuels that need to be imported from elsewhere, and as a result are expensive. Moreover, over 70% of the drinking water on Bonaire is produced by an outdated water reverse-osmose plant, which is far less efficient in water and energy use compared to more recently developed seawater reverse-osmose plants which will be installed in near future. In addition, a large proportion of drinking water is lost during transportation to end users, possibly due to leaking pipelines. The island is blessed with much sun and wind which provide important perspectives for the further development of sustainable sun and wind energy production. In addition, the availability of deep cold waters nearshore, provide possibilities for Ocean Thermal Energy Conversion (OTEC).. By developing of a more efficient water production and distribution infrastructure, and the use of readily available alternative sustainable energy sources can likely provide additional ways to reduce the price of drinking water.

Grey water

Besides the issue of the distribution of treated waste water, water quality is also an important constraint. Within the treatment plant, various treatment steps are used to meet stringent water quality criteria and to it to be used in the hotel gardens at the west coast. When these criteria on nitrogen and phosphorus content are met, coral reefs will be safer from the risk of nutrients leaching into coastal waters. However, at present this "over"-treated water is not being used by hotels, but by farmers, which for their purposes could benefit from the use of less-treated water with higher nutrient concentrations. Farmers at present are using (imported) nitrogen and phosphorus to fertilize their crops. This addition of nutrients to the nitrogen and phosphorus cycle on Bonaire is an un-effective side-effect of the current over-treatment of waste water. It should be discussed among all stakeholders what quality requirements have to be met for different purposes, and to allocate the water accordingly. Maybe, it could be possible to withdraw waste water at an earlier stage in the treatment cycle for the farmers and at a later stage for hotel use.

GOVERNANCE

With proper water management, freshwater availability for various uses can be increased, water prices can be reduced and profitable and sustainable agricultural production can be made possible for Bonaire. The "Bestuursprogramma 2016-2019 Bonaire" and the beleidsvisie landbouw" both pave the way to a more sustainable manner of agriculture, within the ecological limits of the system. The defined action list is long and ambitious but also quite specific. Various defined plans can be financed via the recently declared bestuursakkoord (November 14, 2018), and the allocation of funds are already partly provided via the "regio envelop". Although the plans are clear (more sustainable agriculture, with use of treated water) no concrete actions have yet been defined regarding the underlying water management needs such as as spatial and infrastructure planning. Without a proper and structural vision and actions on future water management, the plans defined in the bestuursakkoord will be difficult to reach.

Water allocation between sectors

As explained above, the different types of water resulting from active water management, can be used for different competing purposes. Therefore, in addition to (a) water production, (b) water quality and the necessary infrastructure for (c) distribution, (d) water allocation between sectors and users will be a key governance matter to address in a water management plan. In particular the allocation of grey water between sectors and their different quality requirements should be discussed and agreed among parties involved (WEB, RCN. OLB, hotels, LVV, farmers,...) and decided in concordance with a strategic development vision for the island. At present water distribution problems constrain which parties have access to treated waste water. Because waste water availability is also not limiting (production exceeds current use), the matter of water allocation is not yet a major issue. However, as soon as the produced wastewater becomes available to a larger group of potential users from different sectors, the matter of equitable allocation will become important.

Figure 4. Groundwater station

FUTURE PRIORITIES & RESEARCH NEEDED

Draft a water management plan, including:

- Groundwater assessment in terms of quality and availability
- Identification of priorities for water retention in relation to coastal impact areas.
- Develop effective systems for long-term storage of freshwater for instance by means of the use of impermeable synthetic lining of catchment dams and basins.
- Design an effective system for freshwater harvest, distribution and use from catchment dams. At present, most water retained behind catchment dams is not actively used and ultimately lost to evaporation.
- Study magnitude and effects of climate change on water demand, supply and quality.

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Colophon

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Nexus interventions for small tropical islands: case study Bonaire

Food from the Oceans

Dolfi Debrot & Sander van den Burg

WAGENINGEN UNIVERSITY & RESEARCH

Food from the ocean holds promise for food provisioning without compromising other dimensions of the water-energy-food-ecosystem NEXUS. Fisheries, near-shore or offshore aquaculture and mariculture can provide valuable resources, produced without fresh water use and with limited use of fossil energy. The most important trade-offs are expected to be related to ecosystem impacts. Sustainable development of food from the ocean does not require technical innovation alone. A multi-facetted approach, consisting of technological development, strengthening human capital and an effective governance approach, is necessary.

	Current state	Desired state	Challenge	Nexus intervention
Fisheries	Limited, but unsustainable reef fisheries, pelagic fisheries is data insufficient (De Graaf et al, 2014/2017 Increasing demand by population and tourism growth	Sustainable fisheries contributing to provisioning of food, lesser imports (energy demand) better diet and	Over exploitation versus sustainable fisheries Stakeholder involvement – shared fact finding Monitoring	Introduction of FADs might lead to sustainable fisheries of the large pelagic fish, with lower demand for fuel, water and less ecosystem impact. Expansion of lionfish fisheries, could benefit the ecosystem but research is needed
Aquaculture	Not existing	Increased food supply, if possible through aquaculture	Sustainable business case	Explore innovative developments such as OTEC or algae parc to build a business case within aquaculture by reducing energy, water use.

Box 1. Summary factsheet Nexus Food from the Oceans.

INTRODUCTION: CURRENT STATE, TRENDS & DRIVERS OF CHANGE

Food provisioning is a known challenge for many small island states. This is due to limited availability of fertile land, a small number of people active in agriculture and often the dominance of other economic sectors, most notable tourism. Still, even though Bonaire is almost fully dependent on the import of food, food availability in quantitative terms is as of now not a real problem. However, food accessibility, quality in terms of vitamins and pesticide residues, actual food use and of long-term stability in availability are issues of concern (Judge et al. 2014).

Food from the ocean is important for Bonaire. In the Caribbean, the quantity of seafood consumed per capita per year is 24 kg per person per year (FAO 2012). This is significantly higher than in the Netherlands (17 kg). Fish is part of the diet and various fish products are available on the market and in restaurants, a mix of imported and local species is found. One can find fishes such as calamares (squid), salmou (salmon) and tilapia next to red snapper, barracuda fillet and grilled wahoo. Especially lionfish is wanted by restaurants. Tourists like to order lionfish as by doing so they feel they are helping to protect Bonaire's coral reef from this invasive species.
In comparison to alternative foods, total consumption of fish is limited by high fish prices. Due to low local production, almost all fish consumed locally must be imported. With a rapidly growing population size, expanding tourism and growing health-awareness, the demand for fish on Bonaire continues to grow. The main drivers for total fish consumption are:

- resident population size
- tourism stay-over visits
- health-motivated food preferences.

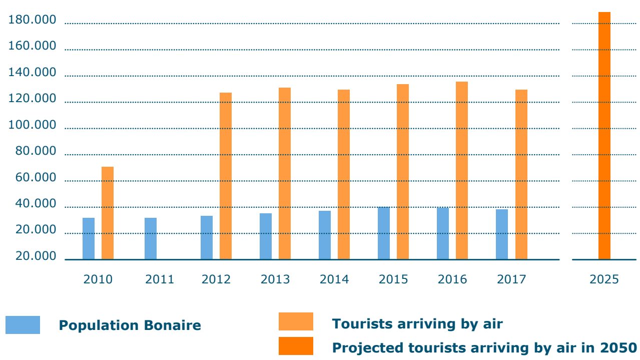


Figure 1. Population of Bonaire (in blue) & tourists arriving by air (in orange) CBS, 2017, with added in dark orange; ambition on tourist levels in 2025

Traditional fisheries play a visible and important role in the Dutch Caribbean islands food systems. Fish serves various functions on multiple levels including food production, poverty alleviation, foreign-exchange savings and/or earnings, recreation and tourism (Agard et al., 2007). Actual employment in the fishery sector in Bonaire is low (de Graaf et al. 2014), most likely because of low profitability. Nearshore demersal fish stocks are very limited due to the narrow island shelf, and have long been overfished.

At present the fisheries of Bonaire can best be described as multi-species, multi-gear, small-scale and strongly traditional fisheries with no major recent innovations (Graaf et al. 2014, Debrot and de Graaf 2019). Aside from motorization instead of the use of sails and the use of nylon fishing lines instead of cotton cordage, practically the same techniques and technology are being used as a century ago. The fleet consists of about 84 small outboard driven vessels and 26 larger diesel vessels with cabin and lengths greater than 7 m. The total annual fish catch for Bonaire is around 103 tons (excluding small shoaling pelagics, which have not been recorded in the monitored catches). Of this about 12 tons is from handline fishing from shore, 30 tons from small fishing vessels and 60 tons from the larger trolling vessels (de Graaf et al. 2016; Tichelaar 2015). All fishing is currently marginal from a business point of view. The average Catch Per Unit of Effort (CPUE) for large vessels amounts to about 1,5 kg (= ± US$ 15) per fisherman per hour. From this all fuel and boat costs must also be subtracted.

The total estimated annual landing of the Bonairian coastal fishery (in 2014) of has a value of ca. 0.7-1 million USD.

Attention has gone out to the development of aquaculture in Bonaire, since the 1950s. Research was carried out on the potential of e.g. tilapia, spiny lobster, shrimp, and clams.. In the 1980s a small laboratory was built to experiment with breeding and release of conch (Lobatus gigas), paving the way for establishment of the Marcultura foundation where research on the feasibility of aquaculture continued. Despite research efforts, there is no commercial aquaculture on Bonaire today. Attempts to set-up a fish farm in 2015 (the Elijah Fish Farm) failed, reportedly due to power failure and subsequent loss of stock. Previously, anecdotal stories tell that efforts to building a proper business case on aquaculture failed due to lack of market potential and mismatch of product offer and product demand, and marketing skills.

Desired future state

Sustainable use of ocean space for the production of food can benefit the provision of healthy food. It can stimulate the local economy and livelihoods, without compromising the other dimensions of the water-energy-food-ecosystem NEXUS. Growth of the fisheries and aquaculture sector for the wider Caribbean is foreseen by the Food and Agricultural Organisation of the United Nations (FAO, 2018)

KNOWLEDGE NEEDS & CHALLENGES

If Bonaire is to realise the same growth in fisheries and aquaculture as expected for the rest of the region (see Figure 2), many challenges need to be addressed. Products need to compete with commodity seafood prices and strong competition from third-world countries. To avoid negative trade-offs, this development must take into account the demand for water and energy and ensure that developments do not negatively impact on the ecosystem.

A key question is to what extent local initiatives can cater to a local food demand and compete in terms of food import prices. Answers to these questions also determine in part whether local initiatives might not best focus on niche markets (Bogaardt et al. 2015), instead of trying to compete with imports from foreign industrial agriculture. Based on the high local labour and utility prices and high cost of feeds importation, it is likely that niche markets can best be served with specialty products.

Fisheries

Practically nothing is known about the stock status of small, alternative pelagic species. Pilot studies are needed to provide basic information on stock status and resource availability (Couperus et al. 2015).

These should be accompanied by trials introducing new technology, such as FAD's and small gillnets for use in flying fish fisheries and as used in the eastern Caribbean. Pilot trials with special traps to target lionfish are recommended to investigate feasibility of developing a directed lionfish fishery. Stock assessments of deep water conch and snapper populations on the east side of the island could help assess resource availability and sustainable harvest levels for these less-fished demersal resources. Critical, also in the case of new and as yet untargeted stocks, is the introduction of effective management systems with which to control fishing and avoid overfishing. Successful examples from the Saba Bank and St. Eustatius can be used as guides to implementing fisheries monitoring and adaptive management (Debrot and de Graaf 2018, Brunel et al. 2018).

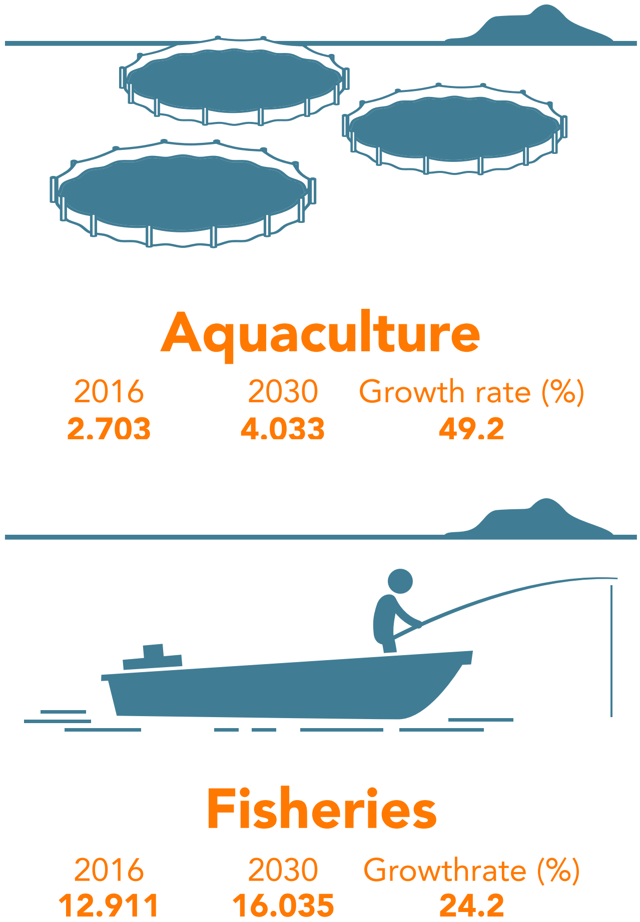


Figure 2. Projected growth rates of fisheries and aquaculture in the Latin America and Caribbean region (production in 1.000 tonnes) (based on FAO, 2018)

Aquaculture

All efforts so far have involved aquaculture on land. The species requiring fresh or brackish water are also problematic due to the low availability of natural fresh water and the high price of desalination. Aside from the protected Ramsar lagoon of Lac Bay, the island has no major areas of shallow sea that are sheltered from the waves. Offshore aquaculture would therefore have to withstand exposed conditions. Potential exists for saltwater aquaculture on land, especially on the low-lying southern part of the island, currently largely in use for low productivity solar salt production.

Currently, there is no infrastructure or value chain to cater to the demands of an aquaculture industry. There is no local food industry that can cheaply provide inexpensive protein feeds for e.g. carnivorous species for which there is also high price competition in the global market. Technical and managerial knowledge needed to successfully run an aquaculture facility is lacking. In order to export products to the regional or global market, additional investments are needed (e.g. cooling houses, logistics).

Mariculture - involving the production of plants (algae and or seaweeds) or herbivores is interesting to investigate, potentially showing more financial potential than mass culture of expensive protein-feed consuming fishes and crustaceans.

POSSIBLE NEXUS INTERVENTIONS

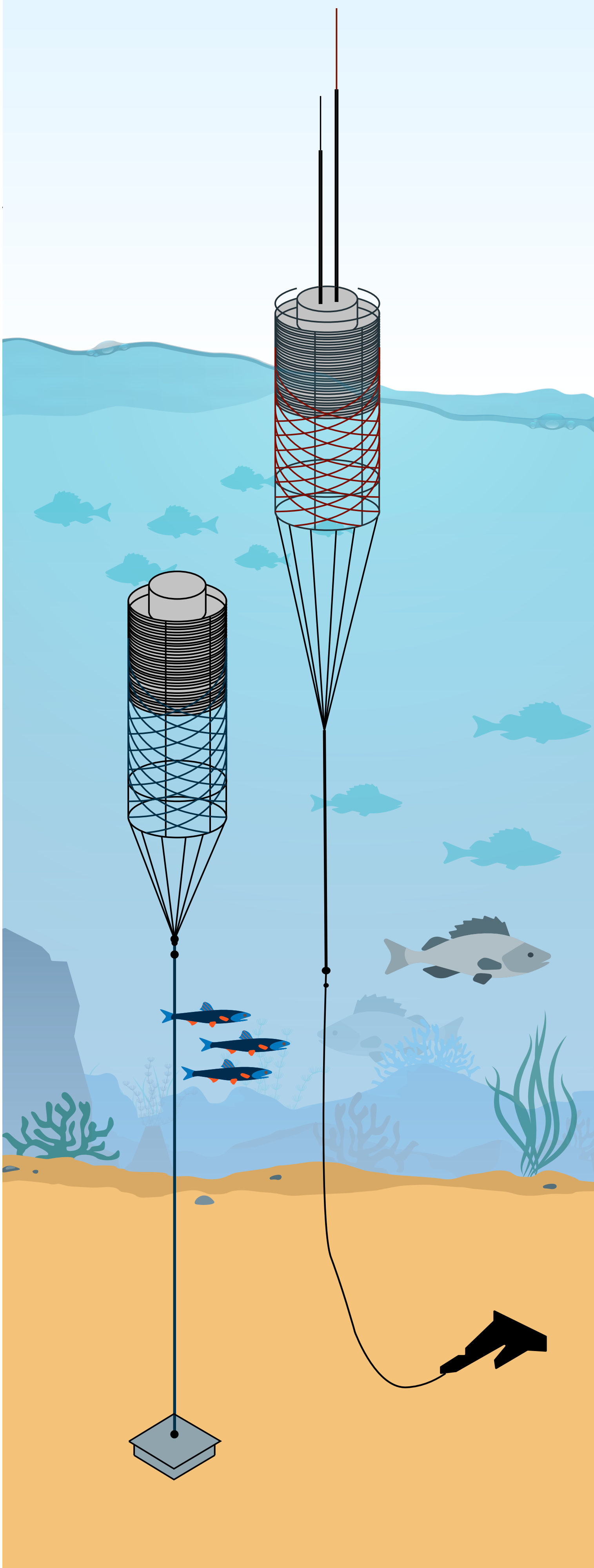
In this section several interventions (Box 2) are presented to improve the provision of food from the ocean in Bonaire, without comprising other NEXUS dimensions, or even to be beneficial to nexus dimensions such as the ecosystem. Note that each exercise comprise the assumption that fisheries and aquaculture should be compliant and be operated within the limits of sustainable fisheries and maximum sustainable yield principles. The main intervention is that several innovations are needed:

Development of fisheries to target under exploited small pelagic shoaling species represent a major opportunity for sustainable food production. As part of the Dutch Kingdom, the Caribbean Netherlands, including Bonaire, have access to EEZ area of approximately 90,000 km^2 of Caribbean Sea which possess various as yet underutilized fish stocks. Almost all fishing is currently directed towards coastal pelagic species and coastal demersal stocks. Prominent among these species with untapped potential are the so-called "small pelagic species" such as various small tunas, shads, flying fishes, needle fishes, clupeids and even squid. It is a major goal of the kingdom parties represented in the formal EEZ Commission and of the 2010 EEZ management plan, to work towards transformation of the fisheries sector of the islands so as to both guarantee sustainability and simultaneously improve local food self-sufficiency for the islands. Assessing potential and developing a small pelagics fishery is highlighted as an important fisheries goal by Meesters et al. (2010) and by Debrot and de Graaf (2019). Couperus et al. (2015) provide an initial inventory of the species concerned and discuss the potential for a small pelagics fishery in the Dutch EEZ. Consumption of small pelagic fish, rather than top piscivores, is more efficient from a biological and an economical point of view.

Pelagic fisheries can be expanded by the the use of FADs. This technology has the ability to concentrate pelagic species to a smaller area close to shore, thereby greatly improving CPUE and lowering engine fuel consumption during fishing. The technology is simple and this type of fishing can be conducted profitably with the current fleet of small fishing vessels and during short fishing trips. Previous experiences with FADs on Bonaire failed due to design in combination with deployment possibilities (Fig. 3). Loss of FAD's mainly occurred due to high vessel traffic and strong currents.

A second type of technology that can be introduced to target small pelagic shoaling species of flying fish is the use of small floating gillnets deployed from drifting boats as commonly used in the Barbados and other islands of the eastern Caribbean (Sobers 2010). This simple-to-apply technology also can be deployed using the present fleet and will not require costly changes to the current fishing vessels.

Figure 3. Basic designs of floating and sumberged Fish Attracting Devices. Left FAD is planned on Bonaire



Expand lionfish fisheries

Lionfish is an invasive species in the Caribbean, inhabiting reefs and deeper waters. Recent research has also revealed that lionfish can tolerate brackish coastal zones, so mangrove and estuarine habitats may also be at risk of invasion. Adult lionfish have no predators, and they are primarily fish-eaters. A single lionfish residing on a coral reef can reduce recruitment of native reef fishes by 79 percent (Albins and Hixon, 2008) thereby potentially affecting the reefs species structure and function. Because lionfish feed on prey normally consumed by snappers, groupers, and other commercially important native species, their presence could negatively affect the commercial and recreational fisheries and dive tourism.

An invasive lionfish food fish market is practical, feasible, and should be promoted (2013 GCFI lionfish workshop). Alternative invasive lionfish end-uses, such as the curio and aquarium trade, are also viable markets. Regarding consumption and the risk for ciguatera poisoning, invasive lionfish ask for a general caution statement displayed within all establishments that serve this species (Johnston et al. 2015).

Explore the potential of aquaculture to contribute to food provisioning. To develop successful aquaculture will require much more in terms of technological development than to innovate the fisheries. Experiences in the Caribbean at large can inform the development of aquaculture in Bonaire. Caribbean aquaculture is characterised by a wide diversity of species and production methods. The geography of these islands are favourable for aquaculture, with long coasts, clear and relatively unpolluted waters. Significant development has been limited to countries like Jamaica and Belize, but other countries like Guyana, Haiti, Suriname and Trinidad and Tobago have put more emphasis on aquaculture as an area for development. All of these are relatively poor countries with low labour costs and in this differ greatly from the situation on Bonaire. "The practices mainly involve the use of ponds to culture such species as penaeid shrimp (Penaeus spp.), tilapia (Oreochromis spp.), carp (Ctenopharyngodon idellus, Hypophthalmichthys nobilis, Hypophthalmichthys molitrix) and cachama (Colossoma macropomum). Also, there is long line culture for algae (Eucheuma spp. and Gracilaria spp.) in St. Lucia and the mangrove oyster (Crassostrea rhizophorae) in Jamaica (FAO, 2018).

Develop seaweed culture for high value markets. There is no seaweed production business on Bonaire, but Bonaire has recently been hit by Sargassum outbreaks, with seaweeds that drift to the islands from elsewhere. This is a local problem; as Sargassum smoothers the coastline, killing seagrass beds that don't have access to light anymore. Sargassum is used for several purposes including as fertilizer, but a problem is that that Sargassum is not available Bonaire on a regular basis, so one need to have an opportunistic business model and early warning systems that takes this into account. One must be able to deal with extreme variability in the accumulation of Sargassum onto beaches and harvests the Sargassum quickly before it decays but also carefully without damaging the beaches onto which it collects. Seaweed culture using longlines as in St. Lucia, as a basis for the production of seaweed products for a niche market (potency elixirs and health food products) could also be explored.

Box 2. Evaluation of possible interventions from a NEXUS perspective

Intervention	Water	Energy	Food	Ecosystem
Develop small pelagic fisheries	No fresh water use	More efficient use of energy for fishing compared to trawling	Provide fish product without using top predators in food web (higher overall efficiency)	Must be managed properly to avoid negative impact
Use of FADS	No fresh water use	Reduce energy use by fishermen	Enhance fisheries	Must be managed properly to avoid negative impact
Explore aquaculture	No fresh water use	Limited energy use during production	Potential source of fish products	Facility must be managed properly to avoid negative impact
Develop seaweed culture	No fresh water use	No energy use in production	Potentially for human food but could also be used for (fish) feed	Potential ecosystem benefits
Innovations (AlgaePark, OTEC)	No fresh water use	Energy could be provided via OTEC, nutrients delivered	Provides water and nutrients to culture fish or other edible species	Impact assessment needed on effluents and other operational aspects
Expand lion fish fisheries	No fresh water use	Limited energy use expected (air for divers, cages), but increase in risk for divers	Provides fish product targeting an impacting top predators in food web	Positive effect on ecosystem structure and function (reef fish) through decreasing an impacting invasive species

INTERLINKAGES WITH OTHER DEVELOPMENTS

The development of sustainable energy generation on Bonaire – for example using OTEC – can reduce the carbon footprint of the infrastructure needed in aquaculture. Building a sustainable business case around (offshore) aquaculture seems only suitable with large investments, and a solid and structural market demand. The development of AlgaeParc Bonaire is interesting in this context, as it is a potential source (water, nutrients, algae) of locally produced fish feed for aquaculture.

GOVERNANCE

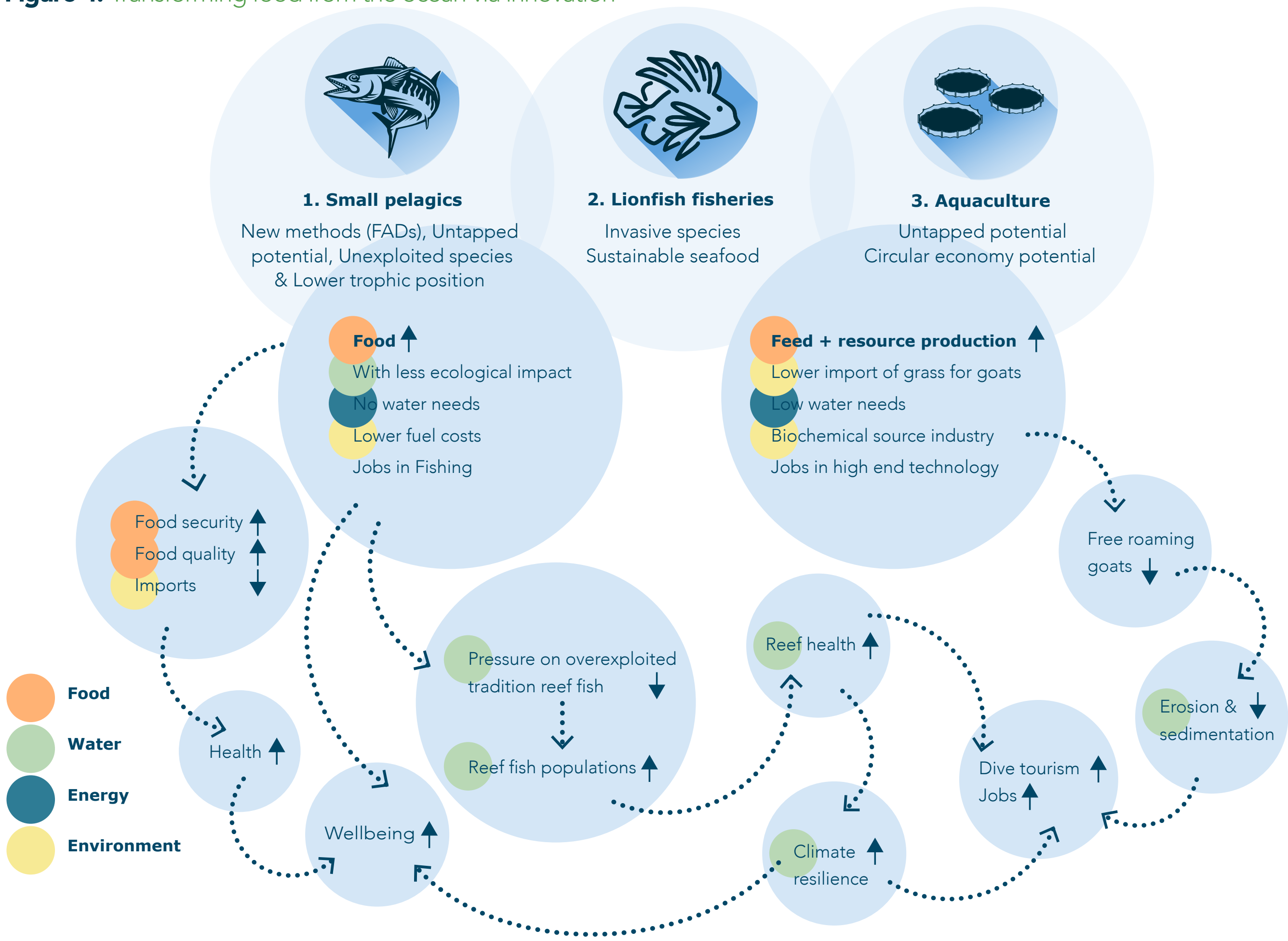
With proper management, simultaneously profitable and sustainable fisheries demersal fisheries are possible in the future. Reef fisheries exert many negative effects on the environment and hence that reef-associated fishing mortality needs to be drastically controlled (Debrot and de Graaf 2019). The benefits of proper management are currently witnessed in the case of the snapper and lobster fisheries of the Saba Bank and the conch fishery of St. Eustatius, all fisheries which have shown consistent improvement of profitability and population status, thanks to judicial management in recent years (Debrot and de Graaf 2018, Brunel et al. 2018). The key to this is to successfully limit total fishing mortality to sustainable levels based on adaptive management.

Controlling and limiting fishing effort for the demersal coastal fisheries of Bonaire, which are currently suffering from heavy overfishing, is a key challenge to improveing sustainable catches in the long term.

Controlling fishing pressure is by far the main factor determining success or failure for sustainable management of Caribbean fisheries. Transforming coastal fisheries towards sustainability is a major challenge towards sustainable natural resource management as well as food self-sufficiency for these severely resource-limited island communities.

In the region, various initiatives to expand the aquaculture sector are underway. This includes investigations into the potential of aquaculture by Caribbean Regional Fisheries Mechanism, support programmes by FAO, and development of best management practices for marine cage culture operations (Price and Beck-Stimpert, 2014). According to Frank van Slobbe (OLB) Bonaire is not interested to be a trial-island for aquaculture. The island is only interested in already-proven ways of aquaculture with limited environmental risks. The focus can include culturing marine algae and seaweeds or selected herbivores and targeting niche markets. Pilot trials and research to test and adapt for suitability under uncommon local conditions and constraints will be essential.

Figure 4. Transforming food from the ocean via innovation



FUTURE PRIORITIES & RESEARCH NEEDED

- Innovation of the fisheries sector and developing an aquaculture sector in Bonaire
- Stimulating entrepreneurship
- Creating human capital / entrepreneurial skills
- Facilitating innovation (financially)
- A first step is sharing of knowledge and making use of experiences in the region

IMMEDIATE RESEARCH NEEDED

Fisheries

- General stock information of all fished species
- Pilot studies on resource availability and stock
- status of alternative pelagic fisheries resources
- Pilot trials with new technology for under-fished pelagic
- Pilot trials with lionfish traps (and learn from recent trap-studies done in the region)
- Stock assessment for deep water conch stocks and deep water snappers on the east side of Bonaire
- Introduction of management systems for new target fisheries to guarantee controlled fishery development and to avoid overfishing ahead of time

Aquaculture

- Pilot trials and research with selected algae and seaweeds of value with low need for freshwater and expensive additives (nutrients and anti-biotics)
- Investigate possible integration between primary producers with herbivorous species (fish and/or shellfish using Integrated Multi Trophic Aquaculture (IMTA)

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Colophon

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WAGENINGEN
UNIVERSITY & RESEARCH

The KB program "Nexus Strategic policy case", included a Bonaire NEXUS case study. The case study was funded under KB-33-005-013, and administered under project number 4318300087. A letter report (number 1900369.ds) summarises the activities. In the study a set of 8 factsheets was drafted (and attached to the letter report). The set of factsheets can be found on : www.wur.eu/sustainablewatermanagement

Nexus interventions for small tropical islands: case study Bonaire

Food from the Land

Matthijs van der Geest & Diana Slijkerman

WAGENINGEN UNIVERSITY & RESEARCH

Like most small tropical islands, Bonaire is largely dependent on imported food. This results in high food prices due to import taxes and transport costs, and high vulnerability towards price fluctuations and global developments, which both present major risks to food security. With many inhabitants living on or below the poverty line, low incomes translate into eating cheap unhealthy food, often causing health issues. While 25% of Bonaire's surface consists of rural areas suitable for on-land food production, current practices of agriculture are small scale, mainly due to small domestic markets and limited access to freshwater, electricity, human capacity and know-how, while the widely used practice of extensive husbandry results in suboptimal yield and severe grazing-induced erosion issues. Sustainable development of agriculture and husbandry on Bonaire thus provides a great opportunity to increase food security, but requires a holistic (nexus) approach that accounts for the local socio-economic setting and the interlinkages between the water, food, energy and ecosystem domains, to identify trade-offs and seek for synergies among these domains. Several nexus interventions are presented that will aid sustainable development of the agricultural and livestock sector, while simultaneously contributing to water, energy, ecosystem and nutrition security. Identified key nexus interventions are: strong policy aimed at facilitation of fenced livestock keeping, water-saving agriculture, decentralized solar power, development of an agro-business and knowledge centre, and development of educational programmes on sustainable agriculture and healthy diet.

Current state	Desired state	Challenge	Nexus intervention
99% of consumed food is imported Unhealthy diet pattern due to relatively high price of healthy fresh food and low awareness of health-risks associated with unhealthy diet High rate of diet-related chronic diseases (i.e. obesities, diabetes) Lack of implementation of food policy by local government Entrepreneurship in food production sector not highly developed Poor transport infrastructure Theft and limited access to infrastructure, freshwater and electricity limit agricultural development in rural area Practice of inefficient extensive husbandry (i.e. free-roaming goats) with suboptimal yield and severe impact on natural habitat due to grazing-induced erosion	A sustainable resilient food system that provides year-round access to affordable, safe, sufficient, and nutritious food, and that contributes to healthier nutrition	Stakeholder involvement Shared fact finding Little financial means to improve transport infrastructure and access to freshwater, electricity, agro-technology, knowledge and human capacity Increasing poverty, which will make it difficult to change unhealthy diet patterns Environmental change (e.g. changing rainfall patterns, sea-level rise, salinization, increasing risk of natural disasters) Low public support for the provision of subsidies to explore the potential of saline agriculture	Strong policy aimed at creating the enabling environment for a sustainable local food production system through facilitation of: • fenced livestock keeping • allocation of (treated waste) water towards agriculture • restoration of dams and husbandry allocation of collected rainwater towards agriculture • decentralized solar power in rural area by providing green loans • development of an agro-business and knowledge centre • access to innovative agro-technology • pilot studies to explore feasibility of using innovative sustainable agricultural technologies (e.g. saline agriculture, hydroponics, reverse-osmose systems, crop selection) • Agricultural diversification to strengthen resilience and productive capacities • Upscaling of existing sustainable agriculture • quality food production and local branding • educational programmes for youth on sustainable agriculture and healthy food consumption • internships and apprenticeships in the agricultural sector • increased utilization of locally produced food

INTRODUCTION

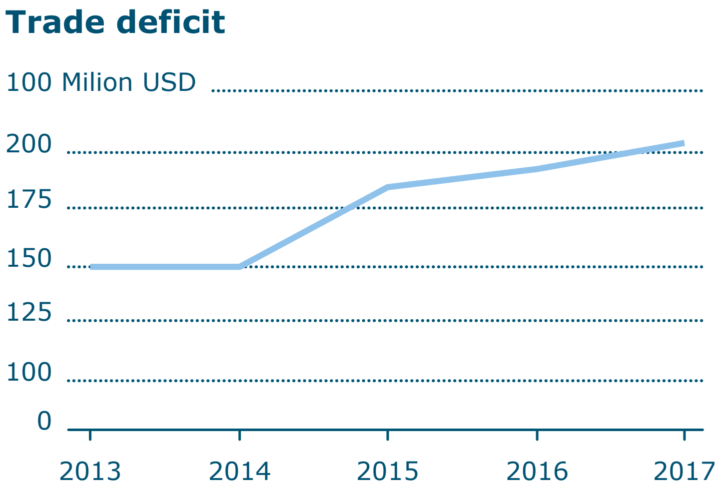
Food security and nutrition is a known challenge for many small tropical islands. On small tropical islands, local food production is often constrained by the arid climate, limited availability of resources (e.g. fertile land, freshwater) and infrastructure (e.g. inadequate ports, roads, storage facilities), small domestic markets, geographical remoteness resulting in very high logistic costs that undermine export led development, and the dominance of other economic sectors, most notable tourism. As such, small tropical islands typically depend on import for their food supply, and Bonaire is no exception. Although this dependence on imported food provides some form of food security, it also creates numerous problems with regard to food security. These problems include relatively high food prices due to import taxes and high transport costs, high vulnerability towards price fluctuations and global developments, significant levels of food loss and waste, environmental and natural resource degradation, and growing malnutrition and public health costs due to the emergence of and preference for more energy dense and convenient processed foods (FAO 2017).

CURRENT STATE, TRENDS & DRIVERS OF CHANGE

On Bonaire, local food production is small-scale and comprises fisheries (discussed in more detail in the factsheet "Food from the Oceans"), culturing of fruits, vegetables and cattle feed, and animal husbandry. Although agriculture forms a large part of the cultural heritage on Bonaire, less than 1% of the economically active population work full-time in the agricultural and livestock sectors (Openbaar Lichaam Bonaire 2014, p.4). The small-scale character of the agricultural sector on Bonaire can be attributed to the arid climate, limited infrastructure, limited human capacity, and limited availability of freshwater: groundwater is mainly brackish, and unsuitable for irrigation of most crops, while watersheds only contain water after heavy rainfall which is restricted to the wet season. Grazing is an additional limitation of crop production. Horticulture for vegetables is only possible in greenhouses, as crops that are grown on open fields will be grazed by parrots, insects, and free-roaming livestock (mainly goats) and suffer from intense sunlight. Greenhouses made of gauze are especially suitable for horticulture, as they allow for regulation of sunlight and as they allow for wind to enter to prevent heating up, while also keeping out insects and other herbivores, but their purchase and maintenance do require additional investments. Moreover, the domestic market is too small to provide significant scale economies, while limited export volumes and distance to larger markets, lead to high freight cost and reduced competiveness.

Bonaire is almost fully dependent on import for its food supply. Fifty years ago, Bonaireans provided for a large part in their own food supply and exported production to Curaçao. However, over the years the self-sufficiency household level has reduced considerably, mainly due to increased welfare, the rise of the status of office work, urbanisation, and globalisation, which made it easier (and cheaper) to buy imported food than to grow it yourself (Bogaardt et al., 2015). The lack of priority by policy makers to develop the agricultural sector, also contributed to the current reliance on imported food. However, small-scale agriculture and animal husbandry still have an important socio-economic function for many people, as they generate an income in addition to their salary or pension (Bogaardt et al., 2015).

Current agricultural practices are extensive, with both investments and profits being low. Local agriculture provides a small part of the market's need for fruit and vegetables, while the livestock sector provides eggs, goat and sheep meat. Only for eggs, Bonaire is self-sufficient (Openbaar Lichaam Bonaire 2014, p.4). As a consequence, on Bonaire, it is estimated that 99% of all daily food products are imported (Openbaar Lichaam Bonaire 2014, p.12). This high reliance on import is reflected by the island's annual trade deficit, which increased to 202 million US dollars in 2017 (see Fig. 1). In 2017, Bonaire imported 37 million US dollars' worth of food products and live animals, which is good for 17.4% of total good imports (213 million US dollars) (see Fig. 1).
There used to be two main import channels: directly from Venezuela via small boats, or through Curaçao. However, since the economic crisis in Venezuela, the arrival of small boats with fresh food from Venezuela has stopped. Those goods shipped through Curaçao come mainly from the US and the Netherlands although some products originate from Colombia, Ecuador, Brazil, and Argentina (Judge et al. 2014). In the transhipment port of Curaçao, food products are being transhipped from container ships to smaller vessels to be transported to Bonaire. **This import-dependent food system results in relatively high food prices due to import taxes and transport costs, and high vulnerability towards price fluctuations and global and regional developments, and thus represents a major risk to food security on Bonaire.** The downside of relying on import, is clearly shown by the 15% increase in overall consumer prices between 2011 and 2018 on Bonaire (CBS, 2018), which can be largely attributed towards global price developments.



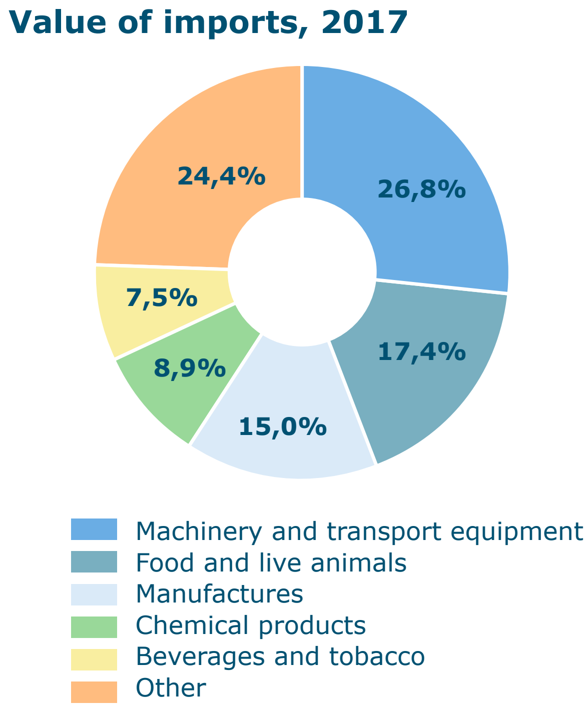


Figure 1. Annual trade deficit on Bonaire in the period 2013-2017 and value of import per category in 2017 (CBS 2018)

The current practice of extensive husbandry leads to sub-optimal yield and severe erosion. The population of mostly free-roaming goats on Bonaire is calculated to be approximately 32.200, of which roughly 40% are unregistered, without an owner (Lagerveld et al., 2015). Other livestock as sheep, donkeys and pigs also graze freely on the island (with or without owners). Together, this free-roaming livestock consume the island vegetation faster than it can regenerate (Roberts et al., 2017). As a result, vegetation cover and root biomass are decreasing, leading to lower water retention and higher soil erosion rates, which in turn reduce growing conditions for plants, and thus food availability for livestock, which increases grazing pressure on remaining vegetation and subsequent erosion rates (see Fig. 2). Not only does this feedback result in sub-optimal yield from husbandry it also amplifies erosion, with subsequent environmental impact on both the terrestrial and marine ecosystems of Bonaire (Roberts et al., 2017). Apart from damage to the environment, free-roaming livestock also cause economic damage to businesses and private individuals, who have to invest in building fences around yards and plots, and by causing dangerous situations in traffic (Neijenhuis et al., 2015). A such, for society the financial gain of the current practice of extensive animal husbandry is much lower than the financial loss caused by grazing-induced ecological damage.

On Bonaire, consumption of fresh fruit and vegetables is low, and diet largely consists of rice, chicken, potatoes and funchi. Beside the relatively high prices for healthy fresh food, education, upbringing, cultural aspects (agricultural work is associated with the history of slavery and perceived as lower class) perception on food (quality of irrigation water) and changes in availability also contributed to the limited consumption of fresh vegetables and fruit. Consequently, overweight and diabetes are health risk factors that are common on Bonaire (CBS, 2018). Wayaká Advies (2018) provided an estimation on the consumption of fruit and vegetables on Bonaire, based on equivalent values of Curaçao. The estimation is that on average, people consume 100 grams of fruit and vegetables per day, which is much less than the estimated average of 127 gram consumed per person in the Netherlands. Based on a population of 22.000 (locals + tourists) this results in a daily demand of 2.200 kg of fruits and vegetables on Bonaire. Assuming that 50% is derived from tins, cans or freezer, a daily demand of 1100 kg fresh food products is estimated (Wayaká Advies, 2018).

In the Policy Vision 2014-2029 Bonaire (Openbaar Lichaam Bonaire 2014) about agriculture, livestock farming and fishing, several actions are proposed for the coming years. These range from the development of sustainable livestock farming and the allocation of land and treated waste water for production of livestock feed, to an expansion of greenhouses in gardens and the development of specific fisheries legislation. In addition, there is the Rural Development Programme (POP Bonaire) and related

[1]Part of the 2013-2017 Nature Policy Plan "Nature funded projects"

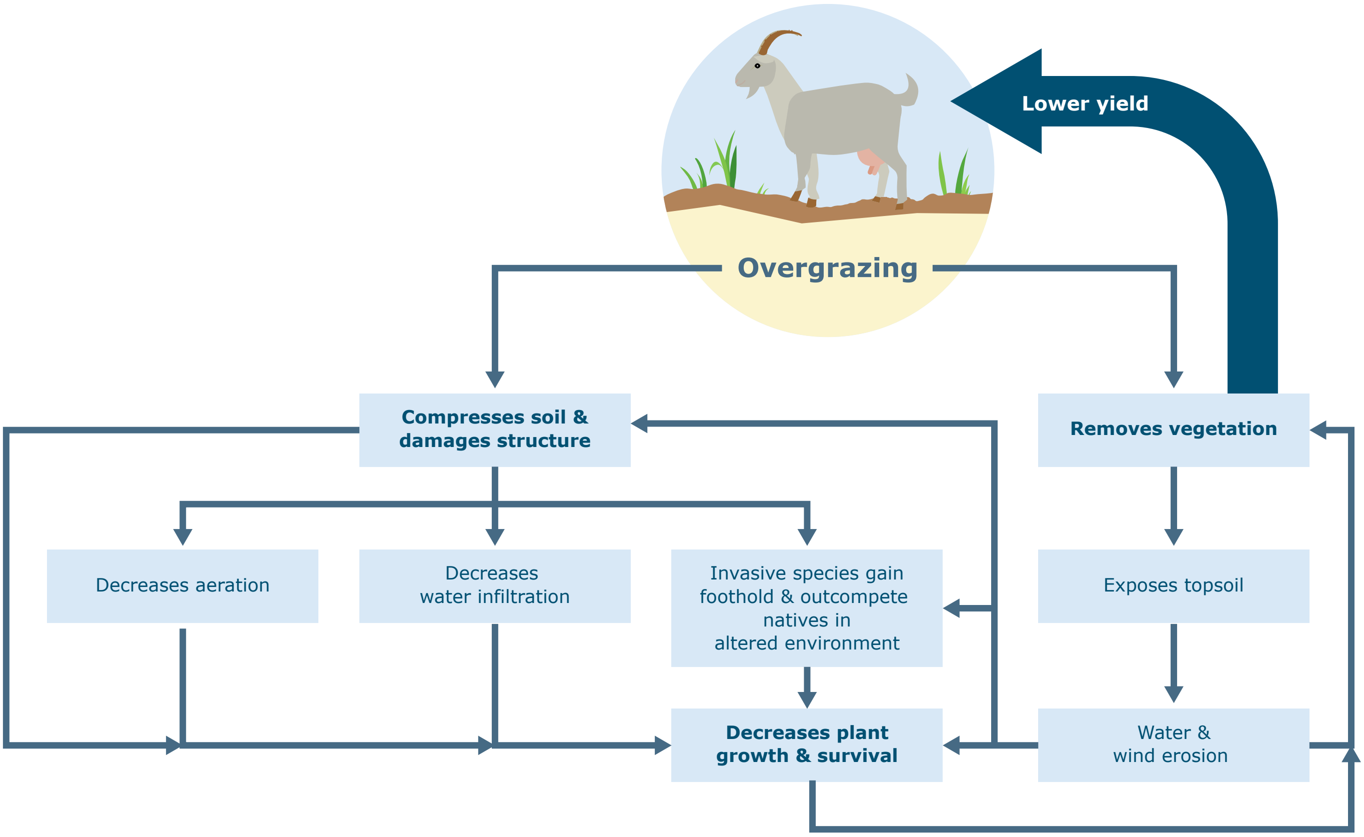


Figure 2. Current practice of extensive animal husbandry on Bonaire leads to overgrazing, which causes a series of feedback loops that intensify overgrazing, eventually resulting in suboptimal meat yield and severe habitat degradation.

project funding[1] that consists of 40 projects that are subdivided into four themes: (1) tourism in rural areas, (2) opportunities for entrepreneurs, (3) vegetables from the own garden and a (4) centre for sustainable agriculture. These POP-projects aim at enlarging the local food production, in combination with nature conservation and focus on education of youth, training of entrepreneurs, guidance and commercial business set-up, development of a centre for sustainable agriculture, but so far the lack of strong policy and governance has limited progress of these projects, which even resulted in the Dutch House's adoption of a motion from the MP Bosman to reorganize the Agriculture, Livestock and Fisheries department (LVV) of the local government to make it more effective (Bosman et al., 2018).

With support from POP Bonaire, a small hydroponic farm has recently started on Bonaire, which has managed to produce affordable crops of lettuce for a competitive price. This water-saving farming technique, reduces water-related production cost of 1 head of lettuce to only 0.04 USD, while the market price for one head of lettuce is 1 USD (pers. comm. Van Almenkerk, Wayaká Advies) and thus provides a great example that investments in sustainable horticulture can also be commercially interesting. In addition to the use of innovative sustainable agricultural technologies, increased food demand as a result of predicted population growth and increasing numbers of visiting tourist, also provides scope for upscaling and commercialization of local food production on Bonaire.

DESIRED FUTURE STATE & CHALLENGES

The aim is to achieve a sustainable and resilient food system that provides access to affordable, safe, sufficient, and nutritious food for everyone, and that contributes to a more healthy eating pattern. This can be achieved by increasing the local food production system in a sustainable way (note that this also includes sustainable development of fisheries, which is discussed in factsheet "Food from the Oceans"). However, to create the enabling environment for development of this desired sustainable and resilient food system, the following challenges should be taken up:

- Low stakeholder involvement
- Rainfall is unpredictable (periods of drought often result in failed harvest due to limited access to water for irrigation)
- Groundwater is unsuitable for irrigation due to high salinity
- Ongoing sea level rise resulting in salinization of ground water
- Increasing risk of natural disasters
- Limited political priority and limited public support for sustainable development of the agricultural sector
- Low public support for the provision of subsidies to explore the potential of saline agriculture
- Limited access to freshwater, electricity, agricultural equipment, human capacity and agro-technology
- High theft rate in rural area limits investments aimed at agricultural development of the rural area
- Grazing-induced erosion by free-roaming livestock leading to habitat degredation and suboptimal meat yield
- 1% of food is locally produced, while 99% is imported
- Low awareness about benefits for health and environment to eat locally sustainably produced fresh food
- Increasing poverty, resulting in consumption of imported cheap unhealthy processed food

Vegetables that can be produced on Bonaire are lettuce, ocra, chard, paprika, pumpkin, spinach, celery, eggplant, tomato, cucumber, cumcumber chikí, garter, tajer leaves and herbs. Fruits that can be produced include shimaruku, papaya, kenepa, medlar, hoba, and coconuts. However, there are also crops that are unsuitable for production on Bonaire due to climatic requirements or high production costs and as such need to be imported. These crops include, cabbages, onions, carrots, broccoli, cauliflower, apples, bananas, oranges, and mango. As a result, a 25-40% production in terms of the total demand of fresh food is assumed to be feasible (Wayaká Advies 2018).

POSSIBLE NEXUS INTERVENTIONS & SYNERGIES

Sustainable development of agriculture and husbandry on Bonaire provides a great opportunity to increase food and nutrition security for current and future generations, but requires a holistic approach that accounts for the inter-dependencies between the Water–Food–Energy–Ecosystem NEXUS domains. In this section, several interventions are presented that will aid sustainable development of the agricultural and livestock sector (i.e. food security), while simultaneously contributing to water, energy, ecosystem and nutrition security.

Sustainable development of goat farming

To reduce the environmental impact of grazing by approximately 32.000 free-roaming goats, unregistered free-roaming goats should be eradicated, which would leave a population of approximately 16.000 goats (pers. comm. van Almenkerk). By replacing these goats with a more productive goat race (more flesh per animal) (Neijenhuis et al., 2015), by shifting towards lamb production (faster yield), and by keeping goats behind fences where they can be fed with more profitable food (faster yield), the remaining 16000 goats can be reduced to 6000 goats while keeping production rates equal (pers. comm. van Almenkerk). These goats will produce higher quality meat, which can be sold for a higher price. To facilitate this change, land and treated waste water should be made available for open-field production of fodder. To compensate for additional costs related to keeping goats enclosed, this fodder should be sold to goat keepers at subsidized prices. As fodder is of higher quality than natural vegetation consumed by free-roaming goats, it will benefit meat quality and slaughter weight, and the quality of manure. Housing of goats also facilitates feed utilization and allows manure to be collected and sold for use in agriculture. In addition, goat housing will reduce grazing pressure exerted by free-roaming goats, which allows natural vegetation to recover. This will reduce the loss of fresh water, topsoil and nutrients from the terrestrial environment and subsequent negative impact on the coastal ecosystem (see Fig. 3 in factsheet "Ecosystem").

Sustainable development of agriculture

The scarcity of water and limited access to renewable energy in rural areas are severe challenges for the sustainable development of agriculture on Bonaire. At present, most water retained behind catchment dams is lost to evaporation. As such, the design and development of an effective system for freshwater harvest, (long-term) storage, distribution, and use in agriculture provides a great opportunity to increase crop yield. Likewise, development of an effective system to make treated waste water available for agriculture will also contribute to crop yield. Moreover, the feasibility of using solar-powered groundwater pumping systems in combination with small solar-powered reverse-osmose units to turn brackish groundwater into freshwater suitable for irrigation, should be explored. At the same time, the use of innovative water-saving agricultural techniques should be facilitated, through subsidies and space allocation for hydroponic farming, saline agriculture and selection of low-water-use crops, and through the development of an agro-business and knowledge centre where information, material and knowledge related to water-saving agriculture can be shared. The development of innovative water-saving agricultural techniques including exploration of production of salt-resistent crops, will likely contribute to agricultural diversification, which will strengthen resilience and productive capacities of the agricultural sector.

Whereas farming requires electricity for irrigation and cooling of products, most farms in the rural area of Bonaire only have limited access to electricity. Facilitation of the use of solar panels by farmers provides an effective way to improve their access to electricity without the need to be connected to the power grid. Moreover, the use of renewable solar energy will make agriculture more sustainable by reducing its carbon food print. Solar panels also provide great opportunities to increase water security when used as collectors of rainwater, and when placed above crops, solar panels can reduce UV stress to crops and reduce evaporation of soils, which both will enhance crop yields. Subsidies and green loans should be provided to stimulate farmers to purchase solar panels.

Refocus on domestic markets

Given ongoing population growth and ever-increasing numbers of visiting tourists, there is much opportunity for agriculture to refocus on domestic markets in order to improve food security and nutrition and advance sustainable development of the rural area. Identifying and realizing real growth market potential in domestic markets, including tourism markets (i.e. quality food production and local branding) and developing production, processing and marketing skills is required to meet the quality and consistency in standards demanded. Exploration of intraregional markets

(Curaçao, Aruba) also represent an opportunity as they enable a faster transition towards new production patterns that could increase equity. Moreover, to increase the utilization of locally produced vegetables and fruit by local people and to increase awareness about diet-related diseases, educational programmes about sustainable and healthy eating should be developed.

Increasing human capacity

Getting young people involved in agriculture and boosting support for farmers is key to improving food security and economic well-being in the medium and long terms. This can be achieved by development of education youth programmes on sustainable agriculture and by encouraging the agricultural sector to provide them internships and apprenticeships. Moreover, a horticultural culture/tradition with local people should build up. All possible by learning in practice, for example by buddying a local for 2 years with an expert in horticulture. Note that in view of the scale of horticulture and hydroponics, not many people need to be trained, because it has to be in balance with market demand. Probably, training of about of 5-6 locals to professional gardeners would allow crop production for the local market in 2.000 to 5.000 m2 greenhouses (pers. comm. Van Almenkerk)

GOVERNANCE

An enabling environment for sustainable development of the agricultural sector is key to achieving and sustaining food security and nutrition on Bonaire. Creating such an enabling environment requires strong sustained political commitment; effective governance and institutional arrangements including meaningful opportunities for civil society to engage and to hold governments to account; the alignment of processes, policies, legislation, systems, regulations, and investments across sectors and levels; the building and mobilisation of sufficient capacity and resources; and the generation and dissemination of reliable and timely knowledge and evidence (FAO 2017).

The challenge is to implement effective and efficient problem solving policies in ways that are regarded as legitimate by the stakeholders who are involved, enabled, or otherwise directly affected by the decisions and actions undertaken by any governance structure or regime, as well as building and strengthening the capacities of national institutions according to priorities (FAO, 2014). For Bonaire, this involves arriving at a shared set of facts among stakeholders to inform decision-making with regard to sustainable

development of the agricultural sector. A key step towards creating a common vision is to bring the various NEXUS-sectors, stakeholders and institutions together and mainstream objectives and concerns to be achieved through integrated NEXUS-approaches.
Strategic decision-making and improved policy development for the agricultural sector of Bonaire is often constrained by isolated, fragmented or missing data. Generation and dissemination of essential data, statistics and information is crucial in order to base policy on evidence rather than perception. Governance as a process of social coordination requires quality assessments and information systems as well as constant monitoring to measure progress. To achieve this it is essential to increase the capacity of institutions responsible for providing food security and nutrition information and consolidating harmonized information systems (FAO, 2014).

Due to the variety of stakeholders involved, governance of the transition towards a self-supporting sustainable food system on Bonaire will be complex. Departments and organisations that play a role in the food sector of Bonaire, including: Department of Agriculture, Livestock and Fisheries (LVV), Boneiru Duradero, Green Bonaire bv, Wayaká Advies, Punta Berde bv, the sewage treatment plant (owned by the local government), Kriabon, Fundashon Forma, Scholengemeenschap Bonaire, Fundashon Krusada, Bona Bista Island Estate, Van Den Tweel Groep, Ministry of Economic Affairs an Climate Policy (via POP), Public Health Service, Rotary Club Bonaire.

FUTURE PRIORITIES & RESEARCH NEEDED

Water management plan: Development and implementation of a water management plan in terms of logistics, water type, spatial and temporal variability in water demand that is aimed at optimization of agriculture without compromising the other dimensions of the water-food-energy-ecosystem NEXUS

Business case saline agriculture: The additional value of a business case for saline agriculture is questioned and should be evaluated. Possibilities of saline agriculture conflicts with local acceptance due to felt inequality in allocated subsidies. In addition, groundwater salinity levels on Bonaire are likely to vary in time and space, while saline crops may require constant salinity. Research is needed to investigate the degree of spatiotemporal variability in groundwater salinity levels and how this variability may affect the potential for saline agriculture on Bonaire and the potential environmental impact of saline agriculture on groundwater quality and quantity.

Monitoring: Current examples in horticulture and hydroponics show that up to 40% of the vegetable and fruit needs on Bonaire can be grown on the island (Wayaká Advies 2018). As this percentage is likely to be insufficient to achieve a sustainable and resilient food system, more investments are needed to increase local sustainable food production. However, this requires knowledge and quality data on where and how to invest in the development of the sustainable agricultural sector on Bonaire, which are currently lacking. For example, to identify suitable locations for development of agri- and horticulture, data are needed on spatial and temporal differences in soil and water quality, moisture, water management, and site-specific logistics and infrastructure regarding access of effluent water to irrigate. Implementation of environmental monitoring programmes will also contribute to shared fact-finding, which will aid stakeholder involvement. Likewise, research into the possibilities of novel water- and energy-saving agriculture are also required.

Socio-economic setting: Through POP-Bonaire, water-saving hydroponics systems and a hydroponic handbook are supplied for a reduced price, which could help to grow vegetables on the household level. However, even small investments for a “Do it Yourself” hydroponic system might not be feasible, and other social-economic factors could limit the potential. Therefore, the acceptance of hydroponics on the household level should be looked into.

Perception of food quality: To increase consumption of locally produced fresh food, the widespread perception that locally produced food is of low quality and not good for your health as a result of irrigation with low quality water, should also be looked into. This also requires quality assessments aspects in terms of medicine, hormones of LVV treated waste water

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Colophon

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Nexus interventions for small tropical islands: case study Bonaire

Energy

Matthijs van der Geest & Iago Teles

WAGENINGEN UNIVERSITY & RESEARCH

Small tropical island states are heavily dependent on imported fossil fuels for the provisioning of energy, and Bonaire is no exception. As a consequence electricity costs are high and vulnerable to oil price fluctuations, which both present major risks to social and economic security. Yet, environmental conditions on most of these tropical islands offer many opportunities for the generation of sustainable energy. For Bonaire these include wind and solar energy, Ocean Thermal Energy Conversion (OTEC) and third generation biofuels (microalgae), which may provide an optimal solution for affordable, safe, reliable, and sustainable energy supply. Apart from differences in development costs and required technical capacity, each of these technologies has their own benefits and shortcomings with regard to land use, water use, and ecological impact. The transition from fossil fuels towards 100% sustainable energy on Bonaire thus requires a holistic (nexus) approach that also takes these interlinkages between water-food-energy-ecosystem domains in to account to identify potential trade-offs and seek for synergies among these domains. Using this approach, on the short term, investment in wind energy and decentralized solar energy seems most ideal, due to relatively low development costs, available technical experience, limited ecological impact and positive impact on water and food security and public support. However, variability of solar and wind power does not allow to make electricity supply fully sustainable. On the long term, 100% renewable electricity supply can only be achieved with OTEC and/or production of third generation biofuels. From a nexus point of view, we recommend to conduct a feasibility study into OTEC, that addresses its ecological impact, and its potential to be combined with Seawater Air Conditioning, fresh water production and microalgae farming to enhance its economic feasibility. Apart from shifting to renewable energy, policy measures directed to energy conservation may also greatly contribute to energy security on Bonaire.

Current state (2018)	Desired state	Challenge	Nexus intervention
69% energy supply from burning fossil fuels (300 heavy oil barrels per day) Remaining supply from renewable energy produced by wind turbines (33%) and solar panels (1%) Energy consumption ~ 110GWh/year (with peak demand at ~16MW) Capacity and quality of the electricity network limits expansion of renewable energy generation	Affordable, safe, reliable and 100% renewable energy supply that is integrated with other resource sectors to reduce trade-offs and provide synergies between water-food-energy-ecosystem domains More efficient use of energy and reduced consumption of energy	Quality and capacity of the electricity network limits expansion of wind/solar energy generation Expected shortage in production capacity **Technical challenges:** - Human capital - OTEC - Replacement of grid - Electricity storage capacity Scale: costs and investment risk on small island Integration with other resource sectors and creating a shared vision	Develop and implement Sustainable Energy vision that integrates the Food, Water and Ecosystems domains to simultaneously aid energy, water, food and ecosystem security Facilitate decentralized solar energy production by subsidies, tomake energy more accessible and affordable for people living in rural areas, with positive effects on economic development and public support for renewable energy **Feasibility studies on:** - Ocean Thermal Energy Conversion (OTEC) that integrates electricity generation with cooling, microalgae production, aquaculture & fresh water production - Microalgae production and processing for biodiesel, feed, fertilizer, cosmetics - Energy storage by means of water reservoirs - Multi-use of solar panels for renewable energy generation, protection of crops from UV, and rainwater collection - Promotion of decentralized solar power on Bonaire - research and policy directed to energy saving through enhanced efficiency, awareness and isolation

Box 1. Summary factsheet Nexus Energy

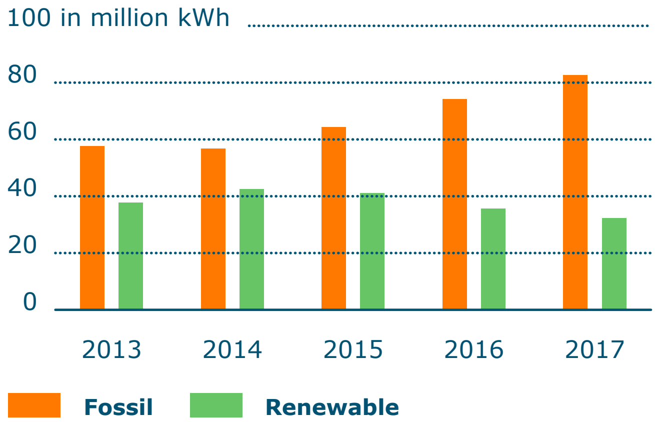
INTRODUCTION

Small Island Developing States (SIDS) base some 90% of economic and social activity on energy derived from imported fossils. Because most SIDS are located far from centres of fossil fuel extraction and production, they have high freighting costs (Thompson, 2016). Their small sizes and population bases also act as a barrier against competitive volume pricing; the creation of economies of scale makes profit generation for power producers and distributors difficult (Thompson, 2016). As a consequence of these combined factors, the energy prices in SIDS are extraordinarily high. As the majority of this energy is used for the production and distribution of both water and food, the high energy price also results in high water and food prices. In addition, burning of fossil fuels contributes to air pollution and climate change though emission of sulfides and carbon dioxide respectively, while storage and transport of oil contains risk of oil leaks. Moreover, the high dependency on fossil fuels make the vast majority of SIDS highly vulnerable to oil price fluctuations, with their economies being hit particularly hard when oil prices rise. Together, high energy prices, high ecological risks, and oil price fluctuations thus present major risks to the social, environmental and economic security. At the same time, the climate on most small tropical islands, offers many opportunities for sustainable energy, such as wind and solar energy. **Replacement of fossil electricity production with sustainable production on SIDS, is thus a very feasible and effective way to reduce energy costs, environmental impact, and economic vulnerability to fluctuating oil prices.** As a result, the current energy policy on Bonaire also aims to provide a sustainable, safe, reliable and affordable energy supply and is focused on the required CO^2 reduction in accordance with the Paris climate agreement (Ministerie van Economische Zaken, 2017).

CURRENT STATE, TRENDS & DRIVERS OF CHANGE

On Bonaire the production capacity consists of generators on oil fuel, wind turbines, a power management system and batteries (to absorb short-term fluctuations in wind production). In recent years, the electricity producer Contour Global Bonaire (CGB) has managed to gradually increase the actual wind share within this production capacity to as much as 43% (on average over 2014, see Fig. 1), which makes Bonaire among the islands with the highest share of sustainable energy worldwide. In addition, in 2015 the Water and Electricity Company WEB Bonaire (hereafter referred to as WEB) has installed a small solar energy plant of 0.20 MW as a test. In 2016, WEB added leased diesel aggregates to meet growing demand. These diesel generators can also run on biodiesel, but currently biodiesel is not available on Bonaire. As a result, the share of fossil energy increased again slightly to almost 70% of the total electricity production in 2017 (Fig. 1). This equals more than 300 barrels of oil used per day, which is a substantial amount with negative impact on energy security and the environment. At the moment, a Green Study is being carried out for further development of the Energy Policy, which is directed towards a more sustainable energy production.

Figure 1. Electricity production on Bonaire between 2013-2017 (source CBS, 2018)



In 2017, the electricity production of Bonaire that was sold by WEB increased to ~110 GWh/year (CBS, 2018) with peak demand varying throughout the year up to a maximum of ~16MW during September mostly due to electricity use for air-conditioning, as this is the warmest period of the year. In January and February, peak demand is at the lowest at ~13.5 MW (Fig. 2).

On Bonaire, all drinking water is being produced by desalination of seawater through reverse-osmose (SWRO), which is an electricity demanding process. As a result, the price of water is closely linked to the price of electricity. Apart from cooling/air-conditioning and the production of drinking water, electricity is also used for production and transportation of food, for example for irrigation of crops. As such the energy sector is strongly connected to the water and food sector on Bonaire. In addition, on small islands like Bonaire, diesel, solar and wind power plants all compete for space with nature, each in their own way, and also can have specific detrimental effects on wildlife and the environment. Given these interlinkages, it becomes evident that energy security is essential for water, food and ecosystem security on Bonaire, as illustrated in Figure 2.

As a result of population growth and economic growth, the energy demand is expected to increase rapidly in the near future, with peak demand predicted to be ~22 MW by the year 2021 (Pers. comm. Hans Staring, WEB). However, the production capacity is expected to lag behind with this growing demand (Fig 3). Moreover, the capacity and quality of the current electricity network is becoming inadequate, possibly also as a result of growth in decentralized generation (Schelleman & van Weijsten, 2016).

In 2016, WEB added leased diesel aggregates to meet increased demand. Nevertheless, there is no spare capacity available in some windless, very warm moments in the autumn. The windmills are then stopped and the electricity demand is high as a result of increased use of air conditioning for cooling. Decentralized capacity of solar panels does not solve this problem sufficiently because one of the two daily peaks in the evening is when there is no solar energy. It is of primary importance that sufficient production capacity with a high availability is placed. In the short term this resulted in more production capacity on fossil fuel. To increase sustainability of this expansion, WEB is investigating the use of more environmentally and climate-friendly fuel (LPG Propane) and more efficient generators, but this is not yet operational. In addition, the current status of the electricity network is not sufficient to meet the growing demand and suffers from disruption and technical grid losses. It seems necessary to strengthen the networks to accommodate decentralized production.

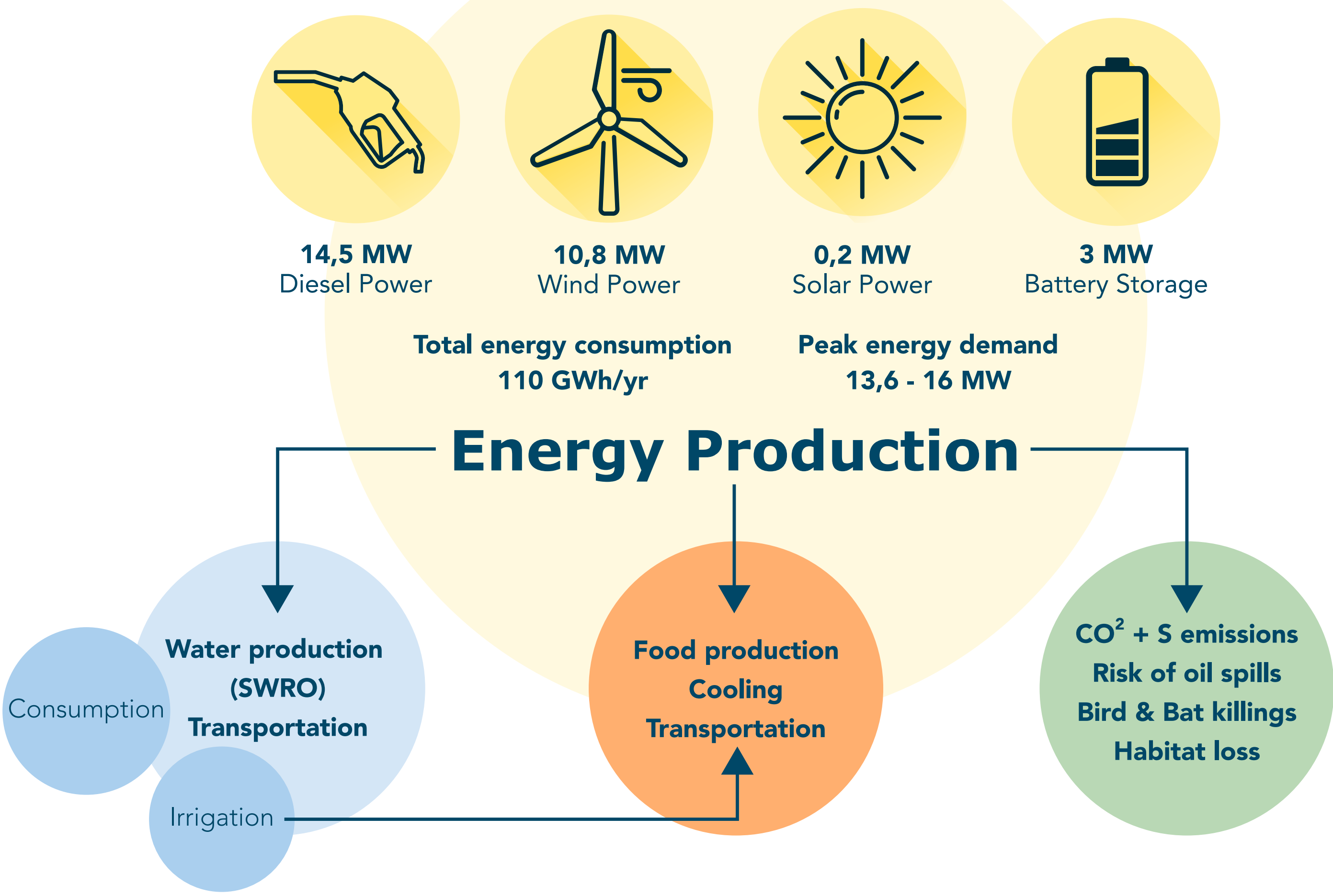


Figure 2. Energy production and allocation on Bonaire in 2017 and interlinkages among energy, water and food sectors and ecosystems.

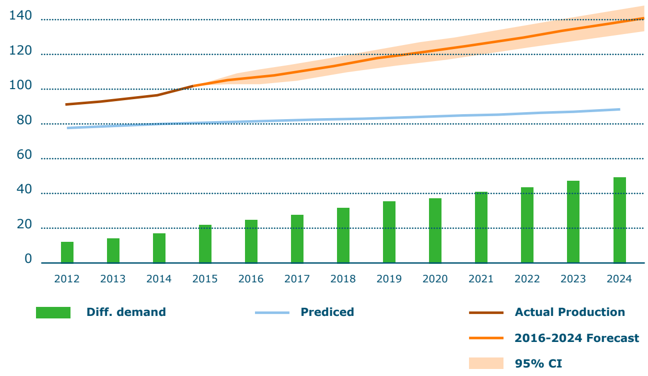


Figure 3. Predicted, realized and forecasted energy demand Bonaire, clearly showing the need for additional capacity (copied from Schelleman & van Weijsten 2016)

The Ministry of Economic Affairs and Climate (EZK) has a strong lobby for development of a second wind park to increase the share of sustainable energy on Bonaire to 60%. This is technically possible, and EZK and WEB have shared vision, but there is still a debate whether solar energy should also be included in the plan for generation of sustainable energy. WEB prefers to invest in wind energy as they already have experience with wind energy production and distribution and effect on distribution network. In order to be able to guarantee energy production, 60-65% energy from wind is maximum according to WEB as this means that you also need to have the capacity to provide energy on days when wind energy supply is limited. It is now technically possible to transport state-of-the art wind turbines that generate 2.3 MW and are 70-80 meter high instead of current wind turbines of 60 meter height, that only generate 0.9 MW. A plan is being developed to place 5 of these wind turbines on Bonaire, which would generate an additional ~11 MW of renewable energy. Additional solar energy is only an option if storage capacity increases, which requires technical innovation, qualified human resources and financial means that are not yet available.

As a long-term perspective and the possibility for a growth path towards full sustainability, an exploration of Ocean Thermal Energy Conversion (OTEC) that generates electricity from the difference in temperature between surface water (> 26˚C) and water at 1000 meters depth (4˚C), and a pilot study on production of third generation biofuels from algae (AlgaePARC) is carried out, the latter in collaboration with Wageningen University. Decentralized production with solar panels also has potential. WEB is drafting the practical rules and conditions and will decide on the basis of experience whether grid reinforcement or other infrastructural measures are necessary to fit decentralised electricity generation.

DESIRED FUTURE STATE

In line with the current energy policy on Bonaire, the desired future state should provide a sustainable, safe, reliable and affordable energy supply that is focused on the required CO^2 reduction in accordance with the Paris climate agreement. Ideally, a transition to 100% renewable energy is achieved that involves the integration of multiple renewable energy resources to improve energy security and create different fields of expertise which will lead to more jobs and increased capacity building on Bonaire.

Based on the findings of the exploratory study 'Renewable Energy Future for the Dutch Caribbean islands of Bonaire, Sint Eustatius and Saba' from research firm Schelleman & Van Weijsten Sustainable Energy Consultancy who identified , wind, solar and Ocean Thermal Energy Conversion (OTEC) as the only suitable options for renewable energy generation on Bonaire, and more recently identified possibility to produce biodiesel from algae as an additional feasible renewable energy resource (AlgaePARC), we have identified possible scenarios from changing the current matrix into a more sustainable one (Fig. 4). Using a nexus-approach, we will discuss the pros and cons of each scenario in relation to food, water and ecosystems in more detail.

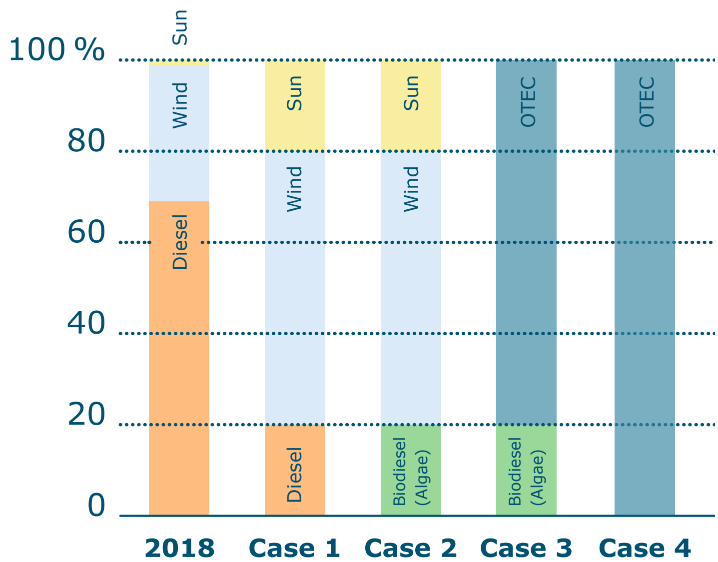


Figure 4. Identified scenarios to make the transition from Diesel-fueled energy supply towards a more sustainable energy supply on Bonaire using most suitable renewable resources (Wind, Sun, Biodiesel from microalgae, or Ocean Energy obtained from Ocean Thermal Energy Conversion (OTEC)

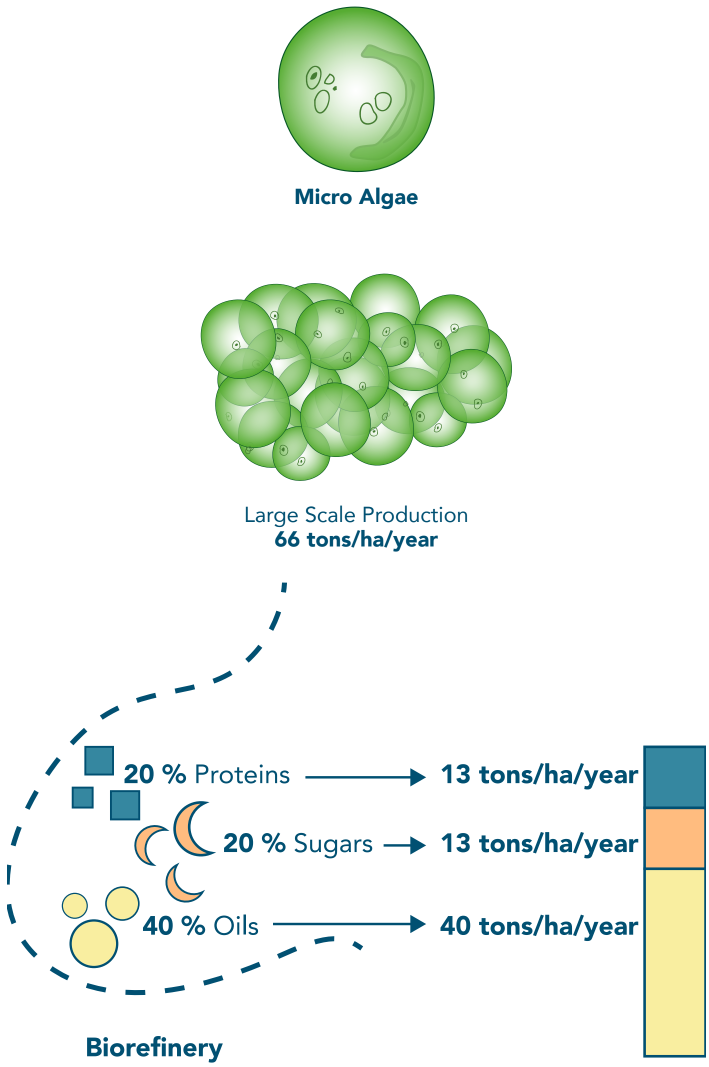
POSSIBLE NEXUS INTERVENTIONS & SYNERGIES

Ideally, Bonaire should reach a 100% renewable energy matrix in the near future. This will only be possible by investing in third generation biofuels and/or Ocean Energy via Ocean Thermal Energy Conversion (OTEC) (see Fig. 4). Whereas biofuels will need to be combined with production of either wind, solar or ocean energy to provide 100% renewable energy supply (case 2 in Fig.4), OTEC has the potential to supply the current demand on its own and to generate a surplus of electricity that should be enough to support new economic activities (case 4 in Fig. 4). Each scenario must follow a thorough environmental assessment of impact to the island resources. The main issue will be use of space, as decision-making includes the choice of where to set such new initiatives. A secured energy supply will guarantee that Bonaire also has a secured water and food supply, which makes the energy sector indirectly/directly connected with local natural resources (water, seawater, and soil), and with other economic activities, such as agriculture, aquaculture, and the current touristic sector (the main economic activity for local residents). Therefore, an integrated approach should be adopted, in which energy is not only seen as an isolated resource, but as the base of all human activities taking place on the island and their impact on water and food supply and ecosystem functioning. Below we describe possible nexus interventions per sustainable energy resource for both the short term and the long term.

Short term nexus interventions

In the short term, investments in both wind and decentralized solar energy together can provide up to 80% of sustainable energy on Bonaire (cases 1 & 2, Fig. 4). Simultaneous investment in wind and solar energy will not only bring more knowledge, industry and jobs for highly educated people to the island, it will also make the energy supply more secure, as on cloudy windy days energy can still be provide by wind, while on calm sunny days energy can still be solar power. Investing in decentralized solar energy systems also provides a great opportunity to let local communities feel the benefits of renewable energy projects and understand their advantages in a more direct personal manner. For example, excess solar power can be sold back to the grid and therefore alleviate electricity bills. This calls or a well-considered policy for the return to the grid. Likewise, placement of solar panels on kunuku's in rural areas that are not connected to the grid will greatly improve life standards of people living there. In this way, decentralized solar energy systems also provide an essential tool in educating local communities about the various benefits of clean energy and climate change. To make the transition to wind and solar energy successful, great priority should be given to increase storage capacity, so that surplus wind and solar energy can be stored for periods without wind and sun. A possible way to store energy is by means of water reservoirs (pumped hydro), which may also benefit water security. In the case of wind energy, care should be taken where to place wind turbines and at what height. The best location and height can be identified by taking in to account both energy yield and environmental impact (i.e. bird and bat killings). In the case of solar energy, solar panels should be placed on existing roofs of houses and other buildings spread over the island to reduce the use of natural habitat and to reduce variability in energy supply to the network. Solar panels also provide great opportunities to be used as collectors of rainwater thus aiding water security. In addition, when placed above crops, solar panels can reduce UV stress to crops and reduce evaporation of soils, which can enhance crop yields, thus contributing to food security.

Figure 5. Maximum yield that can be realized on Bonaire for proteins, sugars and oils extracted from microalgae and used for different commercial applications



Long term nexus interventions

Above a share of 80% in total production, fluctuating solar and wind power is quickly becoming more expensive because disproportionately more storage is required. Sustainability of the remaining 20% with wind and sun is technologically and financially unwise, but could be achieved by investing in third generation biofuels made out of microalgae (case 2 in Fig. 4). Microalgae are small plants, that grow on sunlight, seawater and CO^2, all of which are widely available on Bonaire. They are champions in converting sunlight into different products and fit very well into a circular bio-economy concept. Large scale production on Bonaire can generate 66 tons per hectare per year (pers. comm. Iago Teles). This algae biomass contains 20% proteins (for animal or human nutrition), 20% sugars (for nutrition or industrial uses) and 40% oils (for fuel production, for example, see Fig. 5). Using a biorefinery running on renewable energy, these 66 tons of microalgal biomass can be processed by breaking microalgal cells open to extract different products (i.e. proteins, sugars, oils) with different commercial applications (e.g. biofuel, nutrition, cosmetics).

Unlike third generation biofuels, Ocean Thermal Energy Conversion (OTEC) has the potential to supply the current demand for renewable energy on its own and even generate a surplus of electricity that is enough to support new economic activities. Yet, from a nexus perspective it is more optimal to invest in multiple renewable energy sources as diversification will bring more jobs and increase the capacity building of the island (i.e. cases 2 & 3, Fig. 4). In addition, diversification will contribute to energy security by spreading possible risks associated with each renewable energy resource. A great advantage of OTEC is that it not only allows to integrate different renewable energy sources, but also provides possibilities to link with the water and food sector. **Electricity generation by OTEC can be combined with cooling of buildings (Sea Water Air Conditioning (SWAC)) and fresh water production and microalgae production as illustrated in Figure 6.** The new desalination plant next to OTEC could increase the supply of drinking water and water usable for irrigation (supporting agriculture and local food production), salt would be the by-product, while the airport and surrounding buildings could use cold seawater for air-conditioning. Microalgae production could supply the island with new products, bioenergy, food and feed for animals (for example, for the goats that now can be kept behind fences to reduce ongoing erosion (see factsheet "Nexus Ecosystems"). Specifically, algae can be used to feed fishes, supporting an Aquaculture industry, another source of food for the island. Such scenarios not only supply the demands of the people of Bonaire, but could be further exploited to export products, giving additional income possibilities to island.

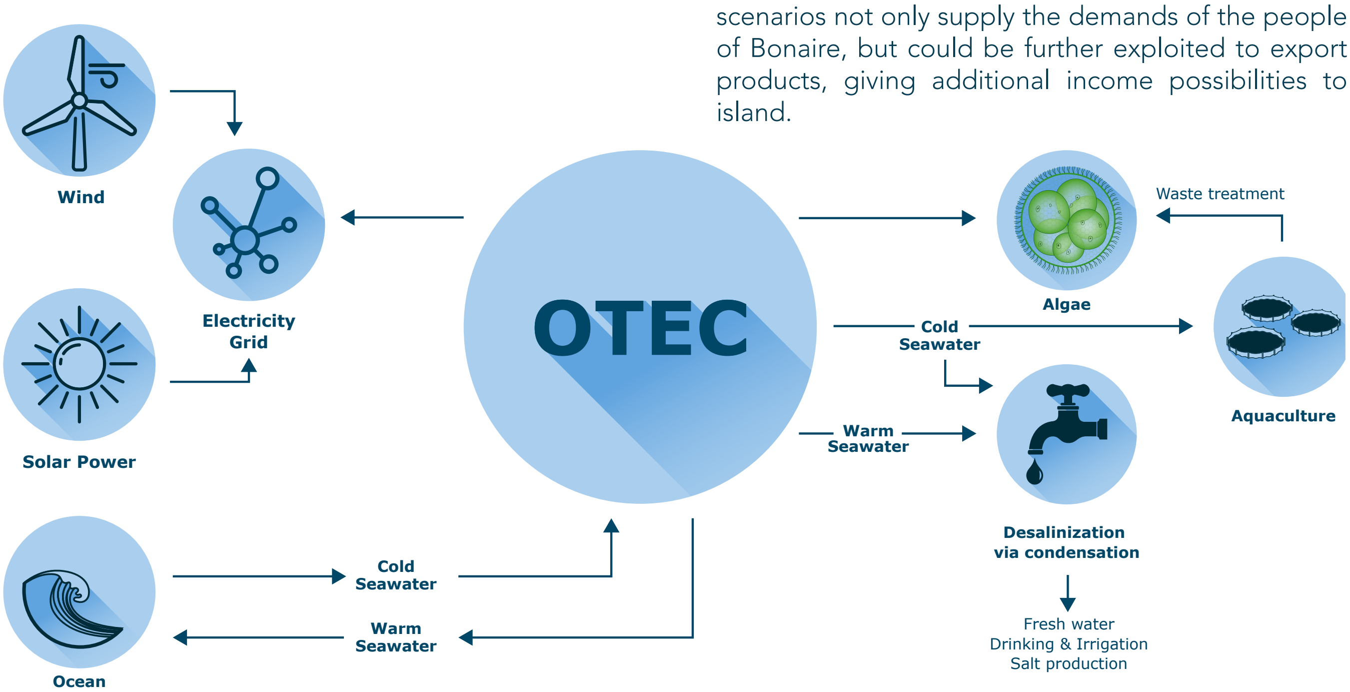
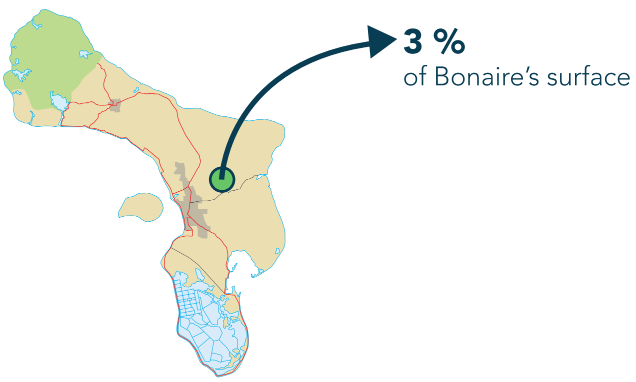


Figure 6. Example of how different renewable energy sources could be integrated to supply the full energetic demand of Bonaire while simultaneously contributing to energy, water, food and ecosystem security

Achievement of both the short and the long term transitions to renewable energy on Bonaire thus requires setting up a multidisciplinary integrated electricity network. This can only be achieved through:

- Provision of specific training for local communities to increase capacity building and prevent brain-drain. Integrate Energy Policy in Ecosystem Based Management plan
- By integration of the Energy Policy in an Ecosystem Based Management plan (see factsheet "Ecosystems", it will be possible to identify the best locations where wind/solar/algae farms should be developed, with regard to minimal impact to nature
- Establish investment projects to diminish risks for further development. For example, facilitate synergism between microalgae production and renewable energies, as illustrated in Figure 6
- Strong policies for sustainable development of the energy sector that is based on shared fact finding. The challenge is how to bring investors and stakeholders. For example, figure 7 shows how much of Bonaire's surface area is needed to replace the current use of fossil fuels (300 Barrels of Oil Equivalent/day) by biofuels produced in Algae farms and what other benefits can be achieved by doing so (pers. comm, Iago Teles)
- Setting stepwise targets for clean energy production. The best solution to avoid detrimental activities for the environment and local communities is to follow a stepwise approach. Targets must be set considering the appropriate scale for Bonaire while keeping energetic demands in mind
- Creation of a governmental funding body focused on clean energy for the region (to make risks lower to attract new capital, expertise and investments.)

Figure 7. Example of what can be achieved when allocating 3% of Bonaire's surface area for production of microalgae.



- **Sufficient electricity for the island**
- **Enough biodiesel for cars & planes**
- **Feed for goat farming**
- **Food products**
- **Potential to an export economy**

IDENTIFIED KNOWLEDGE NEEDS & CHALLENGES

- Qualified human resources: training is needed in all designed scenarios towards a more sustainable energy supply on Bonaire. Special training should be provided to cover the fields of sustainability, novel bio-based technologies, and specific training for each new industrial activities
- Integration of different fields/multidisciplinary approach setting targets. The most successful predicted scenario involves the integration of different technologies, a concept also known as Industrial symbiosis, where different technologies take advantage of the energetic surplus of each other and also can recycle each other's waste streams. Although integration of different technologies and different sectors will support the business case, it will increase complexity of decision-making and implementation
- Costs of bringing so much expertise together. Bringing different expertise's together to a relatively isolated region such as Bonaire can be costly. An advice is to set a network of experts to cover costs of mobility and training. It is essential that such network include stakeholders from the private sector, to guarantee that industrial needs are addressed. A network of this sort could be supported by National Dutch Program or European funds
- Investment risks for such a small market (Bonaire). A program to bring sustainable and bio-based development to Bonaire should include mechanisms (public policy) that could minimize the risks of setting up new sustainable energy sources to the island. Subsidies or public investments must be discussed and included in a broader program. Bonaire's small population is challenging to gather enough investments from the private sector to establish new enterprises. New sources of energy have a special attention in the local development plan, as the current prices for energy and drinking water are way too high considering the local average income

Factsheet 5. Energy 9

FUTURE PRIORITIES & RESEARCH NEEDED

- A full assessment of the integrated environmental impact of bringing a diversified energy grid to Bonaire must be the core of any considered intervention and should take an ecosystem approach combining an environmental and economic point of view (see factsheet 'Ecosystems')
- Assessing OTEC potential and environmental impact on the island. OTEC has the highest potential to supply electricity to Bonaire's grid in the long term. It is also fundamental to support new economic activities. However, OTEC might have impact on marine life, which should evaluated on forehand
- Cost analyses of new energy scenarios to confirm financial sustainability and compatibility with local people's economic power. A full assessment of the costs involved should be made available in future reports, as an additional tool to attract new investments to the island
- Social impact. Social impact for the lives of locals must be taken into consideration

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Colophon

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The KB program "Nexus Strategic policy case", included a Bonaire NEXUS case study. The case study was funded under KB-33-005-013, and administered under project number 4318300087. A letter report (number 1900369.ds) summarises the activities. In the study a set of 8 factsheets was drafted (and attached to the letter report). The set of factsheets can be found on : www.wur.eu/sustainablewatermanagement

WAGENINGEN UNIVERSITY & RESEARCH

Nexus interventions for small tropical islands: case study Bonaire

Ecosystem

Diana Slijkerman, Rene Henkens, Dolfi Debrot,
Matthijs van der Geest & Sander Mücher

WAGENINGEN
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Small islands face various problems hampering sustainable development. Competition for space (land and water) and resources (water, energy, food) leads to various kinds of conflicts that put pressures on ecosystems and not seldom results in ecosystem degradation and lower resilience. This jeopardizes ecosystem functions and thus ecosystem services. However, a resilient ecosystem is crucial for long term food production and water supply.

Free roaming introduced livestock impacts both terrestrial and marine ecosystems via the cascading effects of grazing-induced erosion. Halting this is a key nexus intervention improving the conditions for ecosystem restoration and water retention. Benefits apply to the different ecosystems, agriculture and urban water management. Additional interventions are mentioned.

Current state	Desired state	Challenge	Nexus intervention
Ecosystem provides key services to coastal protection, fish stocks water treatment, pollination, CO_2 sequestration, pest control, tourism and recreation Ecosystem services under pressure through various drivers of change: - Climate change - Urbanisation - Disturbance - Pollution (waste, nutrients, oil, toxicants) - Grazing--> Erosion and sedimentation - Invasive species	Achieving a resilient ecosystem capable of sustaining various ecosystem services and restored ecosystem service levels	Reduce global climate change effects through local measures aiming at increasing resilience by reducing human pressures (pollution, disturbance exploitation) Identify most effective measures through shared fact finding and by evaluating the possibility of using innovative interventions and different usage patterns to reduce human impacts	Implementation of ecosystem-based management across all sectors to maintain ecosystem services Change human behaviour by creating awareness and providing alternative resource use options Upscaling pilot projects - Preventing erosion & eutrophication caused by goats - Lac Bay mangrove restoration Introduce Building with Nature/Nature inclusive concepts: - Management of calcifying algae --> improves sand for beaches - Coral restoration Promote sustainable fisheries

Box 1. Summary of the factsheet NEXUS-Ecosystem

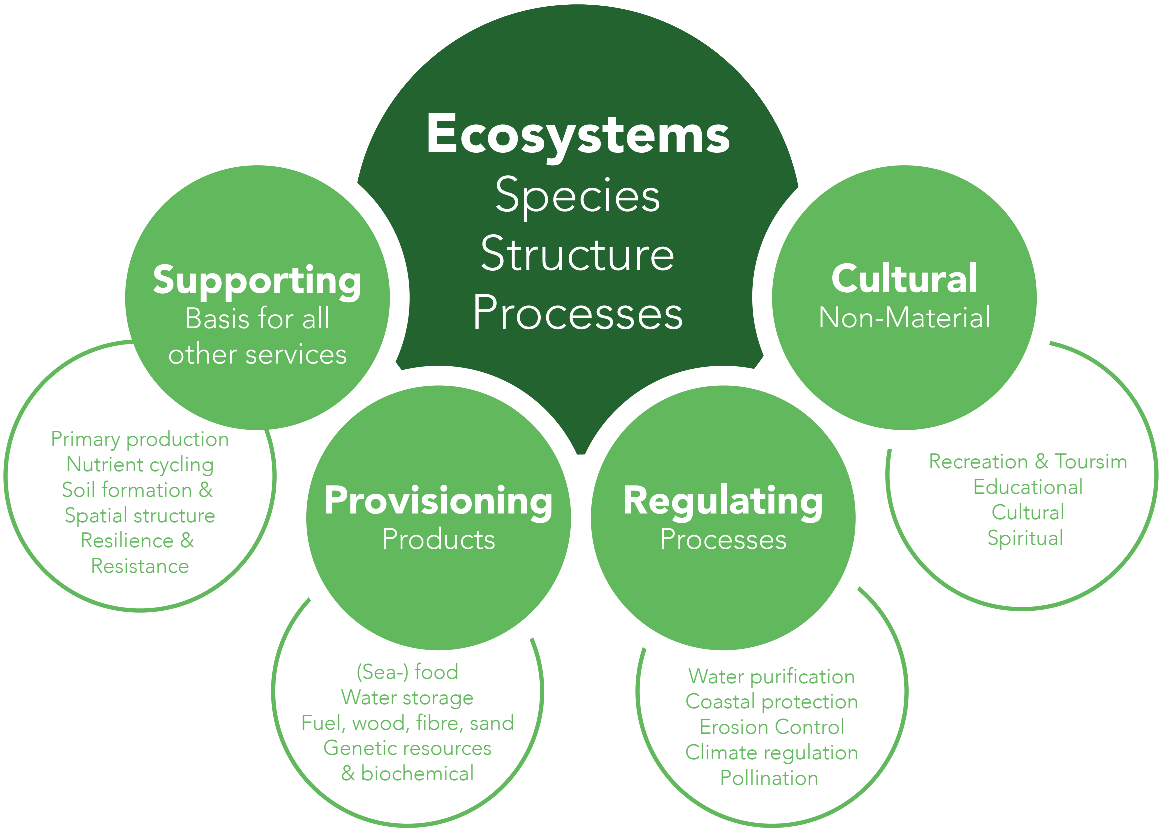


Figure 1. Overview of ecosystem services relevant for SIDS

INTRODUCTION: CURRENT STATE, TRENDS & DRIVERS OF CHANGE

Bonaire is part of the so called Caribbean Islands Biodiversity Hotspot (Myers et al., 2000) and the health of the ecosystems that sustain this high biodiversity, such as coral reefs, seagrass beds and mangroves, are critical to Bonaire society (Van der Lely et al., 2013). This is because these ecosystems provide many 'ecosystem services', which are benefits that humans freely gain from the natural environment and from properly functioning ecosystems (see Fig. 1). There is growing awareness about the economic value of ecosystem services, such as natural coastal protection, fish nursery function, water treatment, pollination, CO^2 sequestration, decomposition of wastes, pest control, and recreational use (De Knegt, 2014). As a result, in recent years, nature policy is not only about ensuring vital nature with rich biodiversity, but also about protection and sustainable use of its services and goods. Small tropical islands, such as Bonaire, are highly dependent on these ecosystem services as nature-oriented tourism and fishing are of great importance to the local economy and wellbeing. For Bonaire, various ecosystem services were identified, and valued in monetary terms. The total economic value (TEV) of the ecosystem services provided by both the marine and terrestrial ecosystems of Bonaire was estimated to be $105 million per year (Van der Lely et al., 2013), which represents ~25% of the gross domestic product (GDP) of 434 million US dollars in 2016 (CBS, 2018).

Although Bonaire has an outstanding biodiversity value compared to the Caribbean region (Van Beek et al., 2014), many threats also put a risk to this quality. Past decades, various local and global developments resulted in serious threats to and rapid degradation of Bonaire's fragile habitats. The main threats and drivers of change are climate change, overfishing, erosion due to roaming livestock, (water) pollution (eutrophication, waste, other pollutants, and recently sargassum pollution), urbanisation, invasive species and disturbance, e.g. through recreation. These factors were recently summarized in the "open Standards" workshops held by STINAPA in 2018, that resulted in STINAPA Open Standards Conservation Action Plan.

If current environmental threats remain unmanaged, the TEV of Bonaire's nature is predicted to decrease from $105 million (2012) to around $60 million in ten years' time and to less than $40 million in 30 years (Van der Lely et al., 2013). When these developments continue unchecked they will continue to undermine the foundations of the island's economy.

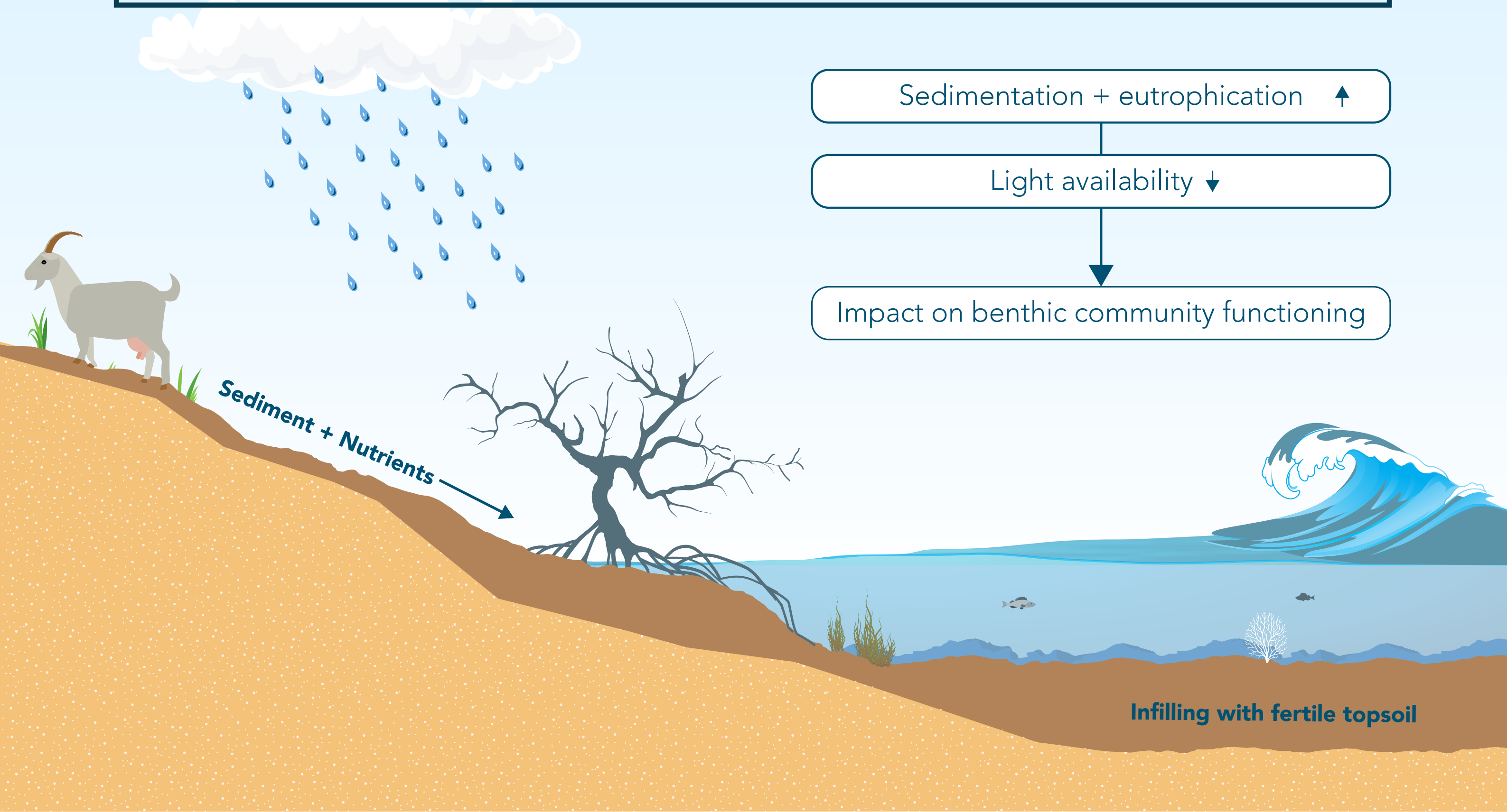
Information on ecosystem components, and the magnitude of the drivers of change, are needed in order to effectively manage and protect the ecosystem's intrinsic value and the benefits it provides to people. However, for Bonaire only very limited structural monitoring of habitats and species occurs, which means that trend data are scarce. Information on trends, future state and drivers of change of Bonaire's terrestrial and marine habitats are listed in box 2.

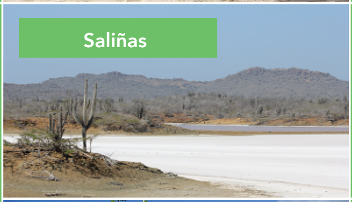
Bonaire, as part of the Netherlands, has to comply with several national and international policy frameworks, treaties and conventions (see generic factsheet). On the national level, the Nature Policy Plan Caribbean Netherlands (2013-2017) aims to ensure that nature on the islands is used in a sustainable way so that the island's ecosystems and ecosystem services can be maintained. The nature policy plan is evaluated and readjusted once every five years. The upcoming nature policy plan is drafted but not yet published (November 2018). The NPP is intended to serve sound decision-making and the allocation of resources and funds. It embraces clear strategic objectives indicating focus areas for adequate nature protection. It provides a framework for the island-specific nature policy plans to be drawn up by the islands' governing bodies. The 'Plattelands Ontwikkeling programma' is a concrete example, in which pilot projects are funded to support nature restoration and sustainable agricultural development.

On paper, most habitats and species of Bonaire are offered some protection in its two national parks, Washington Slagbaai National Park and the Bonaire National Marine Park. Bonaire's fringing coral reefs are amongst the most diverse and healthiest in the Caribbean (Jackson et al., 2014). In addition, other areas are put under special conservation status, e.g. under the Convention on Wetlands of International Importance (the RAMSAR Convention). This is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. Besides RAMSAR, Important bird Areas – IBA- (as defined by Birdlife international) are areas of international significance for the conservation of birds and other biodiversity, but these do not all fall within or coincide with protected areas. IBA sites are part of a wider integrated approach to the conservation and sustainable use of the natural environment. For Bonaire, a total of 5 RAMSAR sites and 6 IBA's have been defined. Of all species on Bonaire, a total 71 species are listed on the IUCN red list, meaning that these species are either critically endangered (CR), endangered (EN) or vulnerable (VU). The protection of 72 species is regulated via Eilandsbesluit Natuurbeheer Bonaire (A.B. 2008, no. 23). These species are either listed on the list of CITES, Bonn-Convention, the SPAW protocol and/or the sea turtle convention.

Society is becoming more dependent on ecosystem services, and more intensive use of one ecosystem service might affect the ability of ecosystem services to function. A well-known illustration is that of roaming livestock, impacting the reef ecosystem via grazing-induced coastal erosion (Figure 2)

Figure 2. Competing claims in the nexus: roaming livestock impacting coastal habitats
Bonaire's agriculture is currently insufficient to secure food supply, while water supply is regulated through the desalinisation of seawater, which is a very energy consuming and thus costly process. The current practice of extensive unmanaged goat husbandry leads to deforestation, desertification and disruption of the hydrological cycles through overgrazing by free-roaming goats. This in turn leads to loss of topsoil (erosion), reduced groundwater replenishment, desertification, extinction of plant species and loss of biodiversity. Overgrazing and coastal development have contributed to severe deterioration of the island's fringing coral reefs and mangrove habitats, which are the main attraction for the tourism industry, crucial to the island's economy. The Fish nursery function of these habitats might be impacted too (Roberts et al., 2017).



Habitats	Bonaire Surface (ha)	Trend and drivers of change
 Tropical dry forest	19.262	**Unfavourable** Indication of unfavourable to bad condition and negative trend (quality), based on increase in urbanisation, grazing and invasive species. Positive changes are reforestation projects and projects targeting roaming livestock (pilot scale). Important ecosystem services are prevention of sediment loss and erosion, retention of fresh water, carbon sequestration, and local climate mitigation.
 Caves	>3	**Favourable (quantity), unfavourable inadequate (quality)** Drivers of change are water pollution by urbanisation and sewage and disturbance (tourism). Both are likely to increase. Ecosystem services are tourism and habitat for bats that are key-species in pollination.
 Beaches	305	**Unfavourable bad** Drivers of change are climate change (sea level rise), visitor disturbance invasive species, pollution (oil spills, marine debris, *Sargassum*) and loss due to construction (building sand) and coastal erosion. Sea turtles and birds depend on this habitat for nesting and/or foraging.
 Saliñas	3.8	**Unfavourable inadequate** Decreasing trend in quality and quantity by infilling (erosion via grazing and urbanisation/ infrastructure), climate change, pollution and disturbance by recreation. Healthy and resilient saliñas provide many important services, such as: stabilisation of sediments, and catchment of eroded soil, thereby protecting the reef from sediment impact. In addition, they are nursery grounds for (commercial) fish, and they mitigate pathogens.
 Mangroves	365	**Unfavourable inadequate** Decreasing trend in quality and quantity by infilling (erosion via grazing and urbanisation/ construction), eutrophication, recreation. Ecosystem services include: nursery area for important commercial fish species, tourism, and nature. Several pilot project aim to restore and protect the mangroves forests in Lac bay.
 Seagras beds	395	**Unfavourable bad** Decreasing trend in quality and quantity due to infilling (erosion via grazing and urbanisation, eutrophication, recreation and invasive species. Ecosystem sediment stabilisation and prevention of coastal erosion, protection of reef ecosystems by settling sediment, nursery function of (commercial) fish, carbon sequestration, production of biocides, filtering of pathogens (Lamb et al., 2017).
 Coral reefs	866	**Unfavourable bad** Decreasing trend in quality and quantity due to climate change, eutrophication, sedimentation, coastal development, overfishing etc. Coverage of living coral decreased with over 50% past 40 years (Fig. 2) (Bak et al. 2005a, de Bakker et al. 2016, de Bakker et al. 2017). Reefs provide many ecosystem services (e.g. tourism, fisheries, coastal protection). coastal protection).
 Open & deep sea		**Unfavourable inadequate** Comprises the sea below 100 m, and is most relevant in size, but also least explored habitat. Related ecosystem services are serving a stabile climate, nursery function for coral reef species (fish, coral, mollusc etc.), healthy fish stocks, foraging sites for birds, migration and living area for marine mammals. Drivers of change are climate change, pollution (waste, noise) and disturbance of geological exploration.

Box 3. Summary of status, trends and drivers per habitat on Bonaire, based on Debrot et al. (2018) and the references therein. Criteria for each status can also be found in Debrot et al. (2018).

DESIRED FUTURE STATE & CHALLENGES

The aim is to achieve resilient **ecosystems** capable of sustaining various **ecosystem** services leading to sustained **water** management, **food** production and **energy** absorption. This can be achieved by increasing resilience by reducing human pressures. The main challenges are to:

- Assess magnitude of climate change impact on coastline and erosion patterns (**food, water, energy, ecosystem**)
- Halt current vegetation degradation and, nutrient, sediment and fresh**water** runoff caused by overgrazing by roaming livestock (i.e. goats)
- Halt current declining trends in fish populations, coral cover and both marine and terrestrial endangered species.
- Restore and create infrastructure for sustainable fresh**water** conservation and use and the reuse of waste **water**.
- Restore key wetland habitat by sustainable mining and reuse of accumulated topsoil and sediments
- Implement new sustainable fisheries and agricultural technologies (**Food**) and phase out traditional unsustainable practices based on overfishing and inefficient freshwater and land use
- Protect coastal habitats from Sargassum loading events and harvest Sargassum for use as a fertilizer in agriculture (**Food**)
- Implement well-structured urban land-use planning to reduce infrastructure, utilities and transportation costs whilst avoiding disturbance, fragmentation and economic development of key island wilderness areas.

POSSIBLE NEXUS INTER-VENTIONS & SYNERGIES

Ecosystem-based management

The main NEXUS intervention would be to adopt an Ecosystem-Based Management (EBM) approach, that recognizes the full array of interactions within en between ecosystems, including humans, rather than considering single issues, species, or ecosystem services in isolation. The current and future environmental challenges that ecosystems on Bonaire face, would benefit from EBM by utilizing a broad management approach that considers cumulative impacts on terrestrial and marine environments, but also looks at ways by which ecosystems can contribute to resource security; an approach that works across sectors to manage species and habitats, economic activities, conflicting uses, and the sustainability of resources. Yet, to be successfully implemented, EBM needs support among all stakeholders, which requires sharing of knowledge, science-based proof-of-concept sharing, and shared vision. This can be achieved by investing in long-term environmental monitoring programmes in addition to scientific research, in addition to the transfer of obtained science-based proof-of-concept to all stakeholders through workshops and educational programmes.

Revisiting ongoing POP and nature fund projects

Using a Nexus perspective, we examined the degree by which existing management measures on Bonaire, create or reinforce positive linkages between the WFEE[1] Nexus sectors. This exercise allowed us to identify whether current management interventions should be abandoned, adapted or extended to increase their significance towards food, water, energy and ecosystem security.

On Bonaire, various pilot projects under the Rural Development Programme (POP) and related project funding (under the "nature funds") aimed at increasing the agricultural potential of Bonaire by restoring terrestrial ecosystems. In fact, without ever putting a "Nexus" name to it, many of these projects already integrated multiple Nexus domains "Water, Food, Ecosystem" to seek synergies between these components and as such, are example projects for the Nexus approach.

One important pilot project focusses on reducing the ecological impact of grazing by free-roaming goats as illustrated in Figure 3. This requires goat keepers to keep their free-roaming goats enclosed. To facilitate this change, land is made available for the production of fodder, which is sold to goat keepers at subsidized prices to compensate for additional costs related to keeping their goats enclosed. As fodder is of higher quality than vegetation consumed by free-roaming goats, it will benefit meat quality and slaughter weight, and the quality of manure. Housing of goats also facilitates, feed utilization and allow manure to be collected and sold for use in agriculture. As a result of goat housing, natural vegetation can recover from free-roaming goats. This will reduce the loss of fresh water, topsoil and nutrients from the terrestrial environment and reduce the negative impact on the coastal **ecosystem** in terms of eutrophication and sedimentation of the coral reef (see Fig. 3). Roberts et al., 2017 provided evidence that coral reef managers could improve reef health through engaging in terrestrial ecosystem protection, for example by taking steps to reduce grazing pressures, or in restoring degraded forest ecosystems.

[1] Water-Food- Energy- Ecosystem

A second project focusses on (re)developing the rain**water** catchment infrastructure (including e.g. culverts, dams) and improve **water** retention, further development of grey water allocation, and help develop water efficient irrigation systems. The re-use for agriculture restored catchment areas will bring increased biodiversity and improve nature development. By reducing the net run off, of water sediments and nutrients, the health and resilience of coastal habitats like mangrove or reefs will improve. Measures taken at Lac Bay by restoring mangrove channels and creating culverts), improves water circulation and quality. The health of the coastal **ecosystems** improves, leading to an optimized ecosystem functioning. To conclude, ecosystem services including fishery yield (**food**), tourism, carbon sequestration, **energy** (wave) absorption (coastal protection), and **water** retention can greatly benefit from the combination of measures taken.

To achieve lasting results, project continuity of best practices is vital. At the moment, the "so-called "nature funds" projects are piloted and small-scale, and run on a relatively short term basis. The effectivity should be evaluated, best practises selected, and the latter could be enlarged by extending the projects and connect them within a catchment scale. Proper project monitoring, documentation, and evaluation is necessary to help consolidate knowledge development and realize progress.

Figure 3. Illustration of Nexus interventions/ measures as described in the text aiming at preventing and restoring impacts by impaired water management, erosion and infilling.

Spatial planning

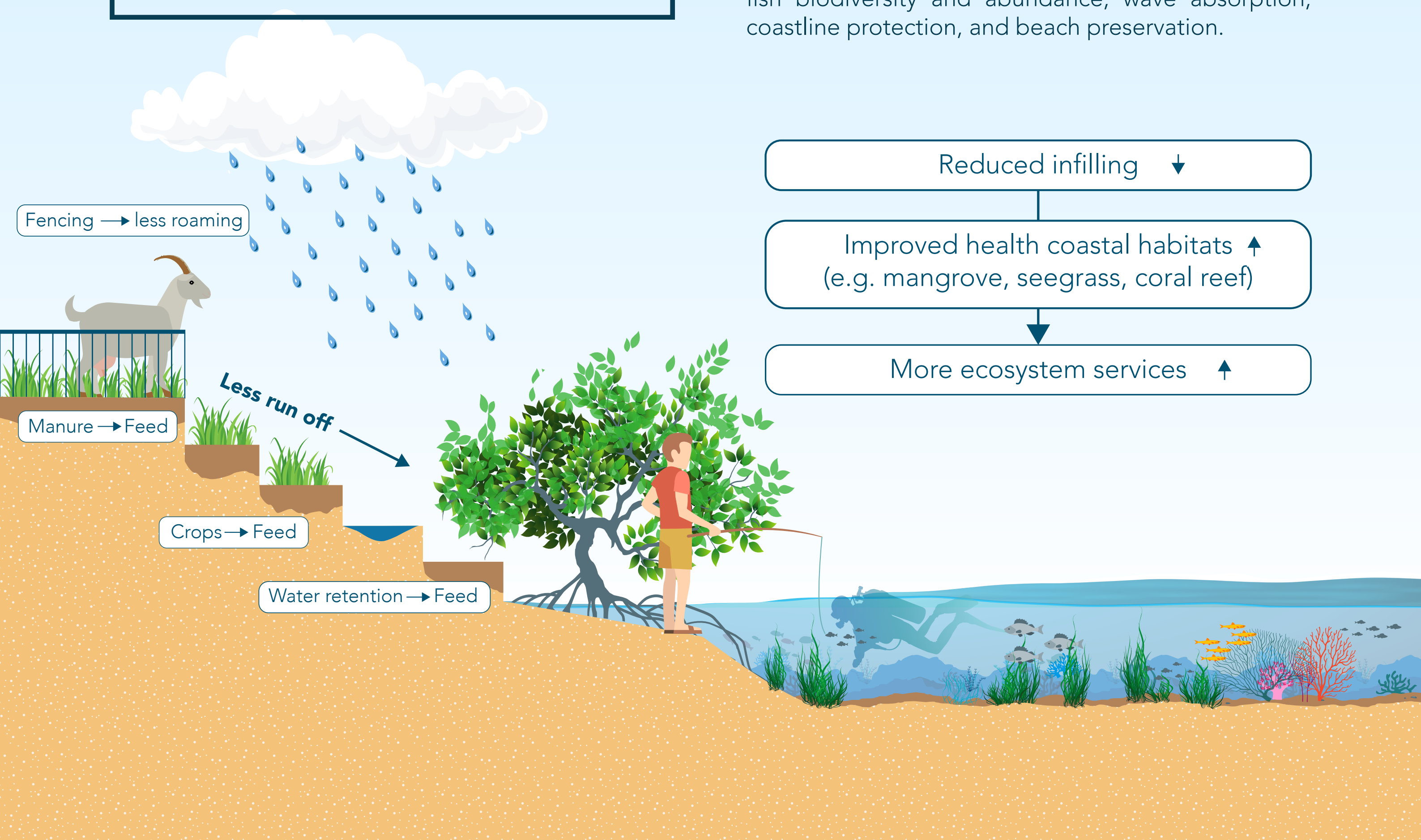
The above presented mosaic of projects/interventions should be brought together to create significance. In addition to that, a more generic intervention would be to develop an integrated urban spatial plan in relation to water management, agricultural and ecosystem needs on the various catchment levels. Projections of historical spatial changes and translating these to potential future changes (e,g, related to climate change, vegetation cover, soil moisture, see "Tools" factsheet) can help to aid a more optimal preparation for the challenges to come

Building with Nature / Nature inclusive building

Building with nature is an approach to engineering that harnesses the forces of nature to allow largely natural recovery of ecosystem function with minimal intervention by man. Below, two examples are presented to illustrate this perspective.

Coral reefs of Bonaire are declining, and the coral restoration project aims to restore populations of Elkhorn and staghorn corals by replanting degraded reefs with nursery grown corals. The subsequent growth of smaller corals into a larger reef system should comprise all the functions a "natural" reef would have. Hence, such an artificially seeded reef should at a certain point become self-sustaining.

Upscaling the project is necessary to increase its ecological significance. Restored reefs will then help restore coral reef ecosystem functions such as fish biodiversity and abundance, wave absorption, coastline protection, and beach preservation.



Sargassum pollution might benefit agriculture

Large quantities of Sargassum accumulate along shores Caribbean Islands, including Bonaire, after large outbreaks upstream. The algae wash ashore, pile up on beaches, and when decomposed, cause the build up of toxic sulfide in the sediment with negative impact on benthic life and potentially on human health. Also, tourism industry is negatively impacted as beaches are temporally not accessible. How to clean up the beaches is a recently discussed aspect among the different countries, including how to prepare for these outbreaks.

From the nexus perspective, this **ecosystem** and climate change phenomenon, could possibly be turned into a potential for agricultural uses, as a **food** source for goats, or as fertiliser or mulch in crop production. These possibilities should be further explored.

GOVERNANCE

The capacity of the ecosystem to supply services, is directly linked to the health of the system (habitats, species, biodiversity and functioning), while the demand of services is the entry point for the socio-economic system (Figure 4) (Gómez et al., 2016). Sustainable benefits provided by ecosystem services often require a production limit (Culhane et al., 2016; Sousa et al., 2016), thus it is necessary to define the differences and conflicts between the demand and benefits.

Since the Nexus domains food and water are based on ecosystem services the inclusion of ecosystems is thus crucial for a proper nexus. Therefore knowledge on ecosystem functioning should be the basis for spatial-economic planning in the water, food and energy sector in order to maximise the benefits from ecosystem services, thereby safeguarding nature management too. Inclusion of ecosystems within the nexus, asks for policy objectives that express the need and sense of urgency in this matter. Ecosystem services can only be restored, maintained or even optimized via good governance, system monitoring, shared fact-finding, adaptive management and by acknowledging the benefits and conflicts.

Results Bonaire visit and workshops

- Management plans, zoning of activities and control asks for shared fact-finding, vision and management measures.
- Implementation of monitoring programs asks for long term funding and capacity of both Dutch and local stakeholders.
- Fragmented governmental responsibilities and four yearly elections, which are mid term political changes result in lack of continuity, stagnated strategy and vision development, and makes a truly joint effort difficult to achieve (workshop results).
- Although successful, pilot projects executed were small scale, and funded for short period.
- Integration, evaluation and professional documentation of results achieved should result in upscaling of best practices, including needed funds.
- This would strengthen their effectives and impact on the ecosystem.
- A common understanding of the value of heathy ecosystems and the ecosystem services it provides towards food, water, energy security and sustainable tourism can be achieved via education and awareness programs.

IDENTIFIED KNOWLEDGE NEEDS & CHALLENGES

Pressures from competing claims (water, food, energy) on the ecosystem, or activities that put an indirect threat to the ecosystem should be monitored and managed. Only then, can all needed ecosystem services be sustained (defined as the main goal in the NPP). A first step is to visualize interlinkages between the four nexus domains (water, food, energy, ecosystem). The lack of data is hampering proper ecosystem assessments, but this is gradually improving. Proper knowledge-based ecosystem based management is now possible. The first step is to fill in the knowledge gaps on ecosystem components (habitats, species, functioning, pressures). This can be done through

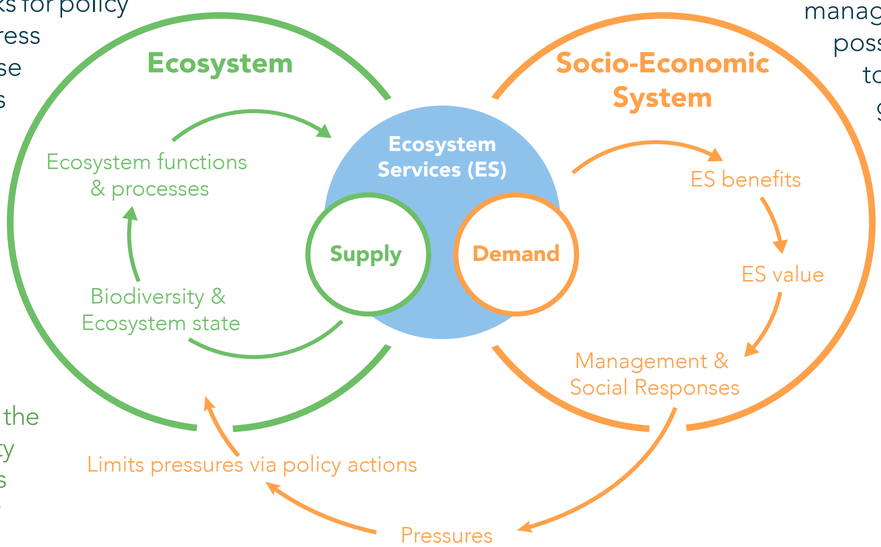


Figure 4. Representation of Social-ecological Systems highlighting the flows from biodiversity to ecosystem services (figure modified after Gómez et al. (2016)

monitoring programs, including remote sensing techniques, shared fact finding and stakeholder collaboration which will also enlarge the acceptance of data and joint selection of best measures.

For evidence based monitoring associated with the scale of ecosystem services, **remote sensing** can be of great help. Satellite imagery can provide synoptic information at appropriate spatial and temporal resolutions. Only at very detailed levels information might be added by using airplanes or drones. In general remotely sensed information can help to provide information on land cover and associated dynamics such as urban sprawl, and habitats such as mangroves and coral reefs, terrain conditions such as elevations and changing coastlines, soil moisture. Also aspects of vegetation (natural and agriculture), such as plant traits, phenology and plant growth can be tracked. Remotely sensed information can make most of the field work more effective associated with ecosystem services.

As illustrated in more detail in the **tools factsheet**, slope and vegetation data derived from remote sensing techniques can be of great importance in identifying erosion hazard, and thus areas of prioritisation for measures such as water storage and erosion prevention. Maps show that most of the catchments with agriculture-Kunuku have potentials of serious erosion hazards with the risk that sediments will reach the coastal waters. Specific measures should be taken to avoid such an impact.

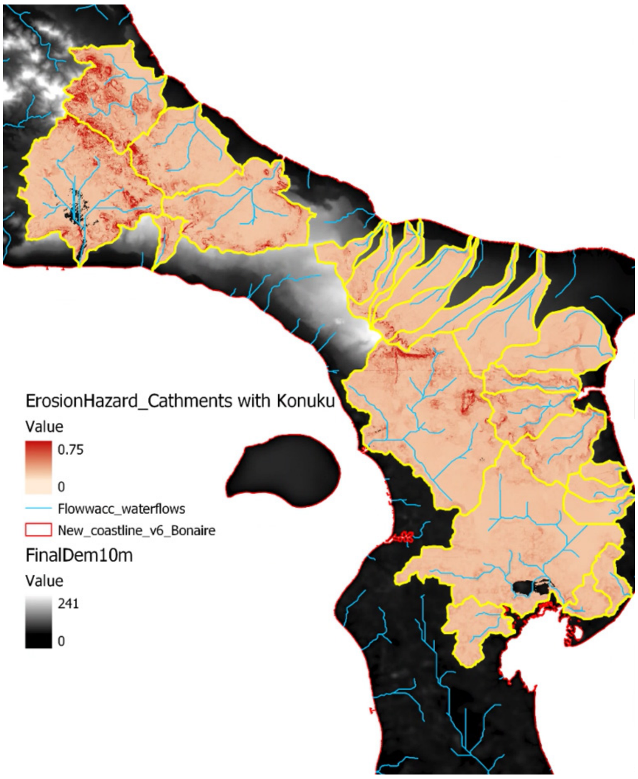


Figure 5. A preliminary erosion hazard map for Bonaire for those catchment areas that are completely or partly covered with agricultural corp / Kunuku

More specifically, and related to nexus domains water, energy and food, the following aspects are a few examples that should assigned in research and management.

Terrestrial ecosystem

- Elaborate on the spatial maps to identify e.g. locations that are prone to erosion or suitable for water storage per catchment (**Water, Ecosystem**)
- Spatial maps based on remote sensing techniques can help identifying best agricultural land (based on slope, vegetation, moisture, erosion (**Food, Water, Ecosystem**).
- Develop sustainable alternatives for agricultural production (**Food**) using drought and salt tolerant (**Water**), preferably native species such as cacti (wine, vegetables, fruits, special diet products) and other succulents and herbs such as (*Salicornia, Sesuvium portulacastrum, Batis maritima*). Attention should be drawn to the beneficiary potential of crop selection towards the **ecosystem** (e.g. in creating a micro-climate, or increased erosion prevention because of their root system.
- Develop freshwater-efficient (**Water**) agricultural production (**Food**) systems (hydroponics, aquaponics)
- Restore old and develop new freshwater catchment systems (**Water, Energy**), thereby reducing sedimentation (**Ecosystem**).
- Develop new, sustainable animal husbandry system and species options (e.g. intensive, penned, livestock husbandry, iguana farms) (**Food**)
- Explore the potential of Sargassum as source for goat feed and fertiliser and mulch (**Food**).

Marine ecosystem

- Sargassum “pollution” early warning system based on remote sensing techniques in order to prepare for harvesting to minimise ecosystem impact, and enlarge the possibilities for re-use.
- Protect, restore and monitor key coastal fish nursery habitats (especially mangroves and seagrass) (Ecosystem) resulting in effects on fisheries (**Food**) and coastal protection (**Energy**).
- Develop alternative fisheries on undervalued and unexploited pelagic species by introducing new fishing technologies (**Food**) and simultaneously reduce fishing mortality of traditional reef fish stocks (**Ecosystem**)
- Develop saltwater (**Water**) aquaculture focussing on primary producers (**Food**) (algae, seaweeds) and primary consumers (herbivores)

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Colophon

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WAGENINGEN
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Nexus interventions for small tropical islands: case study Bonaire

Tourism

Diana Slijkerman & René Henkens

WAGENINGEN UNIVERSITY & RESEARCH

The economy of Bonaire leans heavily on incoming tourism, and depends largely on the values of the blue and green environment. Bonaire has an ambition to increase stay-over tourism with 60.000 tourists in the next 10 years, an increase of 47%. Although tourism development has unwanted impacts on the natural and social environment, the tourism sector is also increasingly recognised as a positive driver of change. From the nexus framework, new insights arise, which include the discussion among all relevant stakeholders of the value and destination of the surplus of waste water that will become available as a result of increased water production and use for tourism. As such tourism plays an important role in the NEXUS-approach. However, sustainable tourism growth should be the basic assumption in tourism ambitions. How to manage and monitor is discussed in this overview.

Current state	Desired state	Challenge	Nexus intervention
Annual number of tourists: Stay-over: 136.000 Cruise ship: 220.000 Ambition: increase of 60.000/year stay-over Pressures increase (habitat loss, sedimentation, pollution, disturbance of species)	Sustainable tourism developmen: make a positive impact on the environment, society, and economy instead of compromising negative impacts on one or more of these aspects.	Safeguard ecosystem intrinsic values and ecosystem services and thus its economic revenue. Sustainable tourism asks for Ecosystem-Based Management, which requires environmental monitoring programmes that are not undertaken yet. Mitigate pressures	Turn the surplus of water produced into valuable waste water destined for e.g. - Crop irrigation - Goat feed - Nature creation Leadership and policy in ecosystem based tourism/ island development.

Box 1. Summary factsheet NEXUS - Tourism

INTRODUCTION: CURRENT STATE, TRENDS & DRIVERS OF CHANGE

The economy of Bonaire leans heavily on incoming tourism. In 2016 the island welcomed almost 360 thousand tourists, mainly through air, so-called stay-over tourism (approx. 136.000) and cruise-ship (approx. 220.000). The direct contribution of the tourism industry to Bonaire's gross domestic product (GDP) is 16.4% (CBS, 2017) which is substantially higher if compared to the average contribution of 10.4% to global GDP (WTTC, 2018). The sector 'hotels and restaurants' generates nearly half of the total value added to GDP from the tourism sector. Recreational activities also play a major role, in particular scuba diving, snorkelling and water sports like wind and kitesurfing (CBS, 2017).

Most recreational activities (e.g. snorkelling, scuba diving) are highly dependent on healthy ecosystems such as coral reefs and their loss would impede a substantial economic loss for the island. Cado van der Lely et al (2013) assessed the Total Economic Value (TEV) of the terrestrial and marine ecosystem services at a yearly $105 million and they estimated a steep decrease to a TEV of $60 million within 10 years' time if conservation efforts would not be intensified.

Figure 1. The UNWTO recognises tourism as a driver for realizing the 17 sustainable development goals (source: http://tourism4sdgs.org/).

The Bonaire tourism sector is aware that its business depends on a healthy environment and it expressed this ambition in its vision "2017-2027 Tourism: Synergizing People & Nature for a Better Tomorrow, The Caribbean's 1st Blue Destination" (Croes et al, 2017). It foresees a tourism growth of 60.000 stay–over tourists in 10 years' time, which is generally in line which the regional growth patterns foreseen by the UN World Tourism Organisation (source: UNWTO Tourism Barometer) and the World Tourism and Travel Council (WTTC, 2018). In 2026 the number of stay-over tourist would then have increased by 47 % compared to 2016.

Though the negative impacts of the tourism industry should not be underestimated (see below), it's obvious that tourism also provides opportunities for the natural and social environment. The UN World Tourism Organisation considers the tourism industry as a driver for realizing the 17 sustainable development goals (SDGs, figure 1), some of which are linked to the NEXUS approach. For instance:

- **SDG 6**. Clean water and sanitation: Tourism can play a critical role in achieving water access and security. The efficient use of water in the tourism sector, coupled with appropriate safety measures, wastewater management, pollution control and technology efficiency can be key to safeguarding this resource.
- **SDG 7**. Affordable and clean energy: As a sector that requires substantial energy input, tourism can accelerate the shift towards renewable energy. By promoting sound and long-term investments in sustainable energy sources, tourism can help to reduce greenhouse gas emissions and mitigate climate change.
- **SDG 12**. Responsible consumption and production: The tourism sector needs to adopt sustainable consumption and production (SCP) modes, accelerating the shift towards sustainability. Tools to monitor sustainable development impacts for tourism, including energy, water, waste, biodiversity and job creation will result in enhanced economic, social and environmental outcomes.
- **SDG 14**. Life below water: Coastal and maritime tourism rely on healthy marine ecosystems. Tourism development must be a part of Integrated Coastal Zone Management in order to help conserve and preserve fragile marine ecosystems and serve as a vehicle to promote a blue economy, contributing to the sustainable use of marine resources.
- Other **SDGs** are however equally important, like SDG 4 – Quality education. Without training and education of local residents many tourism jobs will be fulfilled by expats, leaving the Bonairians behind.

Ecosystems can directly and indirectly be affected by tourism. Pressures are for example habitat loss due to e.g. construction for hotels or trampling of surfaces (seagrass), sedimentation (via construction-induced erosion), pollution (eutrophication, waste, sunscreens), and disturbance of species (e.g. flamingo's, sea turtles). Habitats and species can become stressed, and consequently decrease in quality and or quantity (see factsheet 'Ecosystem Nexus'). A sustainable use of the ecosystem is promoted in order to safeguard its intrinsic value and other important ecosystem services and thus its economic revenue (see factsheet 'Ecosystem Nexus') (Van der Lely et al., 2013).

DESIRED FUTURE STATE: SUSTAINABLE GROWTH

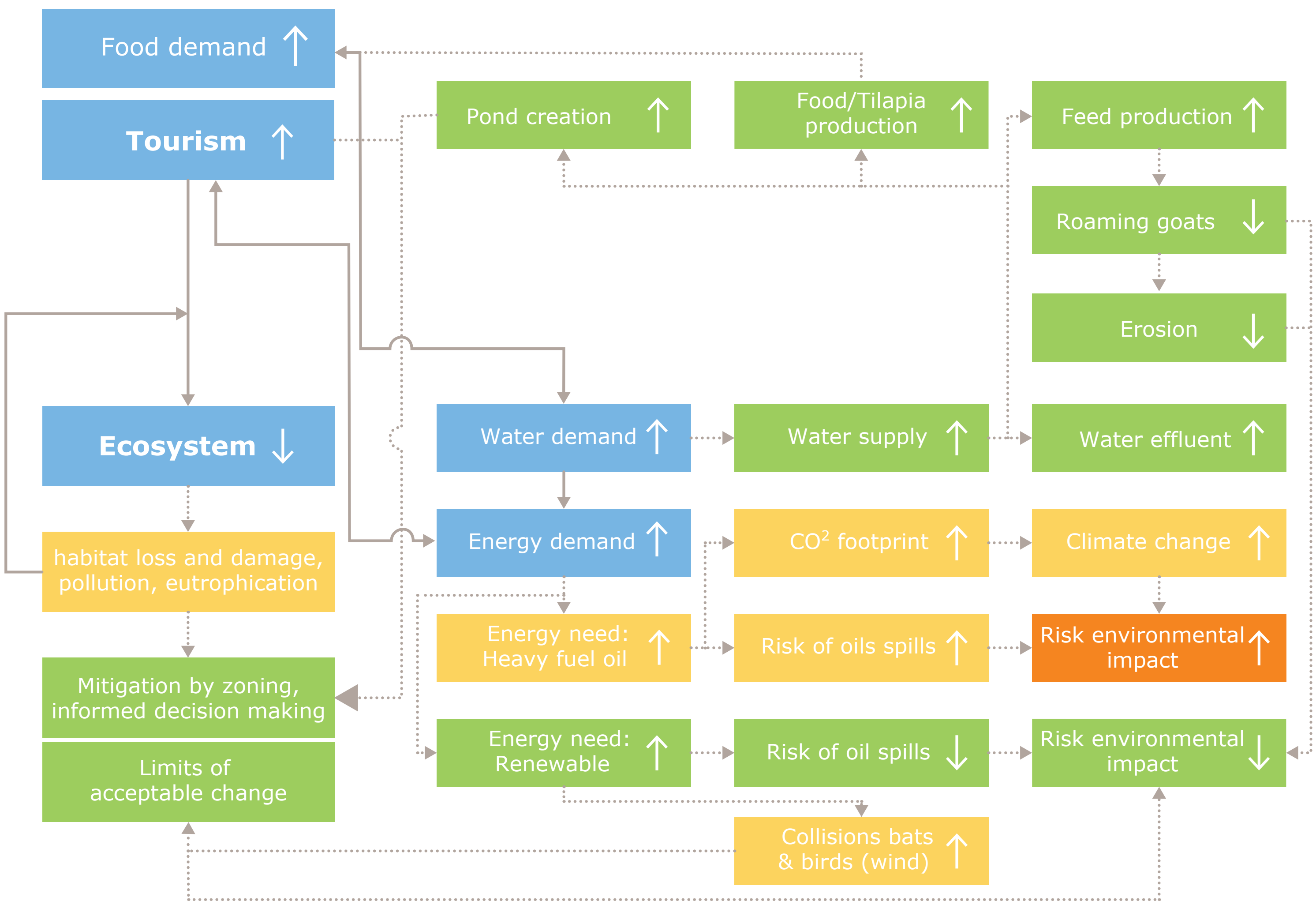
The ultimate aim is sustainable tourism, typified by having a positive impact on the environment, society, and economy instead of compromising negative impacts on one or more of these aspects. In this sheet we focus on the natural environment, as the natural environment is the driving factor for tourists to visit Bonaire.

POSSIBLE NEXUS INTERVENTIONS

As visualized in Figure 2, tourism can have both positive and negative feedback loops in the nexus.

Tourists use relatively much water. Water production on Bonaire is synchronised with the demand, meaning that an increase in tourist numbers will lead to increased production of fresh water (via reverse osmoses). Consequently, more waste water will be directed to the water treatment plant.
On average, each tourist on Bonaire consumes 150 litres of water/day, via e.g. sanitation (showers, toilets), laundry, and consumption (Hans Staring, WEB, personal communication). **An additional 60.000 stay-over tourists will thus lead to a surplus of 9000 m³ water/year.**

Figure 2. Nexus feedback loops from the tourism perspective. Blue: nexus domains. Green: positive feedback loop, yellow/orange: negative feedback loops.



Via a Nexus scheme (Figure 2), the positive feedback loop of increased tourism is visualised towards a positive effect on the ecosystem of the surplus water by tourists. As described in more detail in the corresponding factsheet 'Ecosystems Nexus', free-roaming cattle (goats) are a serious threat to Bonaire's ecosystems as they steer erosion via overgrazing the natural vegetation. Keeping goats in farms would save the natural vegetation from being grazed down, but would require water to produce goat feed/fodder (grass).

Freshwater is limited but the surplus water via increased tourism numbers, and thus increased water from the waste water treatment plant, can be allocated for the irrigation of agricultural land to grow crops for goat feed. As a result, more goats can be kept inside the kunuku's, consequently grazing in nature and subsequent impact of erosion can be reduced.

Table 1. Calculation of the water need by tourists in future, and the value of the surplus of this production in terms of fodder production for goats

In terms of "goat feed", the value of increased tourism can be expressed as: a total of 62 goats could potentially be fed by grass irrigated by the surplus water obtained from the additional 60.000 stay-over tourists. This calculation is based on the table below. Given the total number of 32.000 free roaming goats on Bonaire (Lagerveld et al, 2015), this small number of 62 goats may not seem as a significant added value. However, there are additional benefits from directing the surplus of treated waste water to irrigation of crops for goat feed, as access to this water will make it more profitable for people to start farming again on their often abandoned kunuku's. This will have positive impact on the livelihood of people living in the rural kunuku area, because it will reduce crime (i.e. theft), by increasing security (Lagerveld et al, 2015). In turn, increased security and farming activities, will raise common interest to improve the infrastructure in the kunuku areas, which again contributes to the livelihood of people living there.

What	Amount	Source
Number of tourists		
Current (2016) number of tourist	128,500/year. Equals 352/day	CBS (2017)
Increase of stay-over tourists	60000/year. Equals 164/day	Croes et al., (2017)
Future number of tourists	188500 in 2027. Equals 516/day	Calculated
Water use/demand by tourists		
Current water use/tourist/day	150l/day	WEB, personal communication Staring
Current water use/all tourists/year	19275 m³/year	Calculated
Expected water use/all tourists/year in 2027	28275 m³/year	Calculated
Increased volume of water used	9000 m³/year	Calculated
Water treated and used in irrigation for grass production		
Current volume treated water (2017)	216000 m³/year	WEB data (2017)
Treated water used for irrigation (total)	112000 m³/year	WEB data (2017)
Extra treated water available in 2027 through increased tourism	9000 m³ / year	Calculated (assumed equal to the extra demand and supply in water by tourists)
Water required per day for irrigation of 1 hectare of grassland		
Current use of treated water for irrigation grassland	40 m³/hectare/day	Pers communication Van Almenkerk
Land that can be irrigated with extra treated water (+ 9000 m³) available in 2027	0.62 hectare	Calculated
Relating fodder production/hectare to fodder consumption per goat		
32 hectares of grasslands feeds 3200 goats	1 hectare/100 goats	Pers communication Van Almenkerk
Number of goats that can be fed with fodder produced on the 0.62 hectare irrigated with extra treated water supply in 2027	62 goats	Calculated

However, this example shows just one Nexus intervention. In addition, figure 2 illustrates also other nexus feedback loops to be explored.

- Instead of directing it to agriculture for irrigation of fodder crops, the surplus of water can also be directed to other end-users, including:
  - Horticulture (aquaponics).
  - Ponds, which will attract birds and birdwatchers, like at the Bubali wetlands at Aruba.
  - Ponds, to grow freshwater fish (e.g. Tilapia) for human consumption However, the added value and suitability for consumption of fish has to be studied.
  - Revegetation programmes.
- The demand for extra water results in an increased demand for energy to produce fresh water. Choices should be made between heavy fuel oil, or renewable energy as source. Each choice has its own consequences on the CO2 footprint, oil spill risks etc.
- The feedback loop "ecosystem demand" is elaborated in the next section.

The man-made Bubali wetland, Aruba

The wetland of Bubali (83.6 ha) is located on the north-west coast of Aruba. It is a former salina which receives effluent from the waste water treatment facility since the early seventies. The wetland has transformed in a mosaic of permanent open water, reed beds and mangrove forests. More than 120 bird species are recorded, often numbering several thousand during peak migration periods. As such, the area is a wetland of international importance, which is due to be designated as a Ramsar site. Apart from birds the site also attracts many bird watchers, which contributes to the local economy.

KNOWLEDGE NEEDS & CHALLENGES

Surplus water

The surplus of water can be directed to various end-users. The allocation of water, and knowledge needs are further elaborated in the factsheet 'Water Nexus'.

Sustainable tourism growth

In order for the tourism sector to contribute to sustainability goals, it must be formalised what sustainability means. Debrot et al. (2019) assessed the current conservation status of all habitats and species in the Caribbean Netherlands. Yet, goals should be set about the preferred conservation status of habitats and species, like the percentage of life coral cover, the density of seagrass beds or the population number of (indicator) species.

Depending on the status, the limit of acceptable change should be set. E.g. with the current decreasing trend of cover and quality, it can be debated whether or not a continuing decline is acceptable. Also, a positive trend alone, like for the current increasing number of yellow-shouldered parrots, is not enough if its numbers are still below a set limit of acceptable change (LAC): currently its population is still small and threatened. In addition, care should be taken towards the so called "shifting baseline".

Such thresholds or LACs are known from the European Netherlands, like for fisheries species (Figure 3; CBS et al. 2018). Carrying capacity studies are an alternative manner.

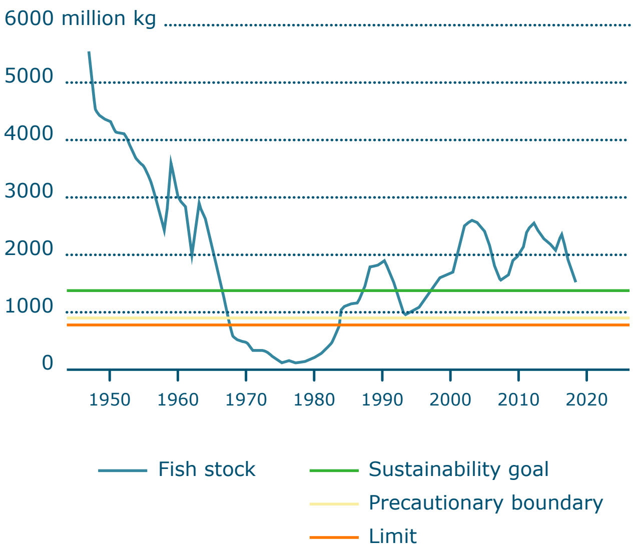


Figure 3. Example of a Limit of Acceptable Change (LAC) for the Herring in The Netherlands. The yellow precautionary boundary indicates a population level beneath which measures should be taken (LAC), while the red-purple boundary indicates the level beneath which reproduction failures are to be expected. The green line represents the sustainability goal (CBS et al. 2018).

Measures must be taken if the conservation status of habitats or species surpasses a certain LAC. This can be measures in different fields, preferably measures that mitigate the most substantial threats. This might be tourism, but the threats from free-roaming goats, invasive species, pollution or fisheries are often much more substantial (Debrot et al., 2018). These threats should be monitored as well, like for major threats in The Netherlands (figure 4).

The analysis of both long-term trends of nature indicators and its major threats indicates which measures should be taken to achieve a sustainable conservation status of the natural environment in combination with its exploitation. The complex relations between habitats, species and its threats request a modelling approach. The Meta Natuur Planner (MNP) is the model developed by Wageningen Environmental Research and used by the "Plan Buro voor de Leefomgeving (PBL) to assess the state of nature. It provides policy advise through publications like the national Balans van de Leefomgeving (PBL 2017). Other options are semi-quantitative modelling of risks and impacts (see factsheet 'Ecosystem'). These generic models might have added value for small tropical islands, by helping to assess and set the level of sustainable exploitation such as tourism.

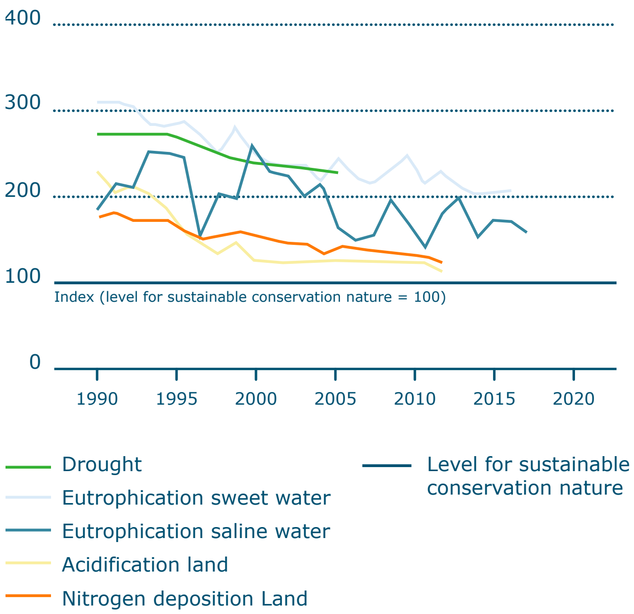


Figure 4. Example of long-term monitoring of major environmental threats in The Netherlands, like drought, eutrophication and acidification. The 100-line indicates the level below which the impact is considered to threaten the conservation status of nature.

GOVERNANCE

It is currently unclear who is setting the goals for sustainable tourism (e.g. number of people, number of cruise ships). Sustainability limits should be discussed in terms of ecosystem, social (residents) and psychological (experience value) carrying capacity, and limits in managerial capacity. Is this a responsibility of the tourism sector (cooperate social responsibility) or should the Island Counsel set strategic goals for sustainable tourism development?

Leadership: allocation of long term biodiversity monitoring responsibilities, budgets, capacity, and lab facilities. What is the role and responsibility of the Netherlands and the Island?

STINAPA plays a central role in management of marine and terrestrial nature on Bonaire. Besides that, they are key stakeholder in tourism development as they are financially dependent on nature fees and thus the number of tourists. This potential controversy can conflict with the ambitions and responsibilities of their co-stakeholders under the Blue Destination ambition, the Chamber of Commerce and Tourism Board, which both have interest in tourism growth from an economic and social perspective. Shared fact finding and vision could be key in sustainable future collaboration.

TO CONCLUDE & WAY FORWARD

Ecosystem services are key in the Water-Food-Energy-Ecosystem Nexus for small tropical islands like Bonaire (see factsheet 'Ecosystem'). Drafting nexus linkages from the tourism perspective provided new insights on the provisioning of fresh water, and the allocation of the surplus water produced to the ecosystem or agricultural landscape. Next step would be to discuss with all stakeholders, what the most beneficiary and efficient allocation of surplus water could be.

Sustainable development of tourism requests shared fact finding, for which long term monitoring on values (ecological and economical, pressures and stakes) should be the basis. Leadership, capacity, strategy and allocation of budget are key issues that are currently missing.

Research agenda

- Communication with all stakeholders (which goals, how, who, set up, results) in order to increase shared fact finding and shared measures in future
- Long term monitoring of habitats, species, pressures:
  - Develop indicators for sustainable tourism for the Caribbean Netherlands, like the many indicators available on biodiversity and threats at the Environmental Data Compendium for the Netherlands (https://www.clo.nl/)
  - Set budgets
- Select responsible departments and allocate capacity

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Colophon

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Reviewer: Matthijs van der Geest

Graphic design and lay out: Kinga Bachem

WAGENINGEN UNIVERSITY & RESEARCH

The KB program "Nexus Strategic policy case", included a Bonaire NEXUS case study. The case study was funded under KB-33-005-013, and administered under project number 4318300087. A letter report (number 1900369.ds) summarises the activities. In the study a set of 8 factsheets was drafted (and attached to the letter report). The set of factsheets can be found on : www.wur.eu/sustainablewatermanagement
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Nexus interventions for small tropical islands: case study Bonaire

Remote Sensing Tools

Sander Mücher, Nafiseh Ghasemi, Wouter Meijninger, Henk Kramer, Bert Lotz

Smalls islands are especially vulnerable to climate change and land use changes due to the competing needs for limited resources. To support the NEXUS approach we need evidence based monitoring tools that can provide policy makers, conservation managers, entrepeneurs, scientists and the general public with information on the state, pressures and associated changes in the environment. Satellite imagery can provide synoptic information at appropriate spatial and temporal resolutions that can support evidence based monitoring. Only at very detailed levels information might be added by using airplanes or drones. Remotely sensed information can help to provide information on e.g. land cover and associated dynamics such as urban sprawl, mapping habitats such as mangroves and coral reefs, surveying terrain conditions such as soil moisture conditions and erosion hazards associated within catchments, sea level rise and changing coastlines, and on many aspects of the vegetation (natural and agriculture), such as plant traits, phenology and plant growth. Remotely sensed information can in general make field surveys and monitoring more effective, and can thoroughly support decision making.

INTRODUCTION: CURRENT STATE, TRENDS & DRIVERS OF CHANGE

Since small islands like Bonaire are especially vulnerable to climate change and land use changes due to the competing needs for limited resources, it requires a holistic "Nexus approach" that considers the inter-connections between water, food, and energy sectors in relation to ecosystems. In recent years, the Water-Food-Energy-Ecosystem (WFEE) Nexus has emerged as a powerful concept to capture these interdependencies between ecosystems and the water, food, and energy sectors, and is now a key feature of policy-making (Leck et al 2015). In all these Nexus sectors remotely sensed information can be of great help. The amount of satellites and associated camera systems have increased enormously during the last decades making them fit for much more application domains. Moreover, many satellite data has become available as open source data in easy accessible archives. Small islands require in general detailed information at finer spatial resolutions. Nowadays there are many satellite sensors that can fulfil this requirement with spatial resolutions of 10-25 meter or much finer resolutions of commercial satellites such as 0.5 m on which individual trees or cars are visible. Due to the high frequency of recordings, from monthly, weekly to almost daily, the opportunities for monitoring have increased enormously. In cases that even more detailed information is needed this can be supported by airborne images from manned or unmanned vehicles. The last are also known as drones. In principle, spaceborne data is much cheaper to use than drones, although the latter can be easily applied for small areas and hot spot monitoring.

In this factsheet we concentrate on Bonaire as an example showing the way how remote sensing tools can provide useful information. A reason to concentrate on this island is that Bonaire is part of the so called Caribbean Islands Biodiversity Hotspot (Myers et al., 2000) and although many habitats are well protected they are still under much pressure. Bonaire has only limited structural monitoring of its environment, including its natural habitats and urban environment, which means that trend data are scarce. Such monitoring requires basic maps on the spatial configuration and current state of the environment, including land cover, habitats, terrain conditions, etc. We will show that remote sensing can play an important role to generate those basic maps.

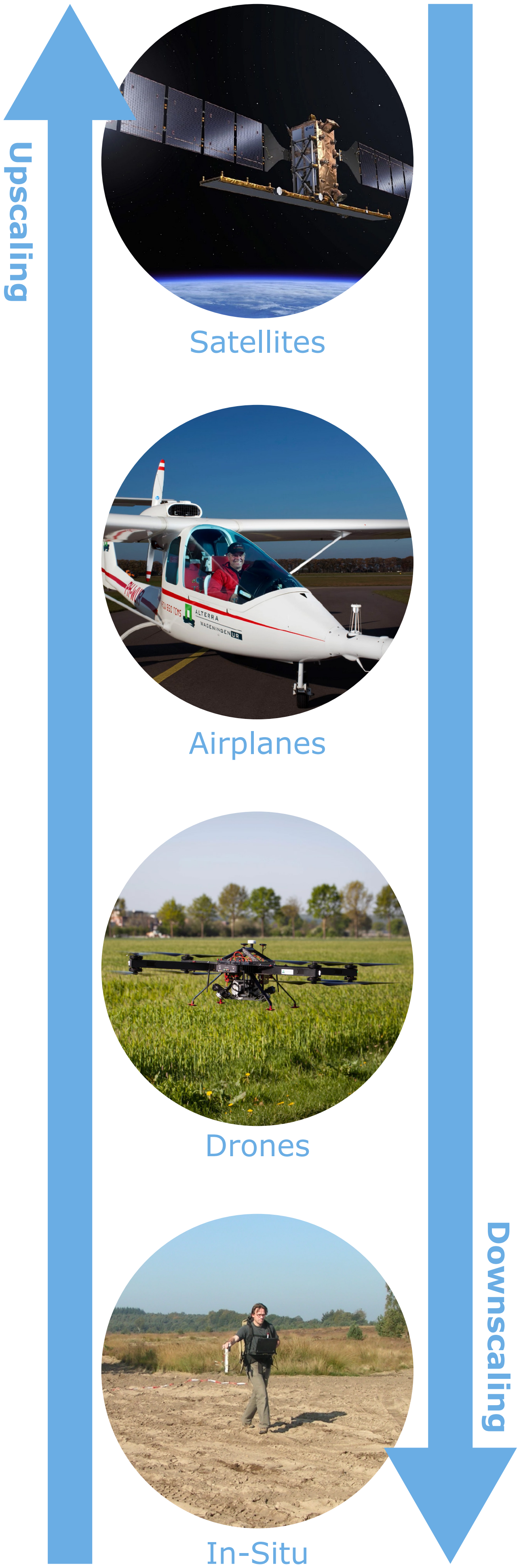


Figure 1. Multi-scale remote sensing

PRINCIPLES OF THE TECHNOLOGY

Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation (Lillesand et at al., 2008). Remote sensing involves the exploitation of electromagnetic energy sensors from airborne and spaceborne platforms that assist in inventorying, mapping and monitoring of earth resources. Visible light is only one of the many forms of electromagnetic energy. Radio waves, heat, ultraviolet rays and Xrays are other familiar forms (Lillesand et at al., 2008). Irrespective of its source, all radiation detected by remote sensors passes through some distance the atmosphere, and is influenced not only by the sun and target angle but also influenced by atmospheric effects as scattering and absorption. The figure below of hyperspectral imagery shows that very targeted material, like soil, water and vegetation have their own specific reflectance curve of the electromagnetic radiation, and these so-called fingerprints helps to identify those specific thematic objects.

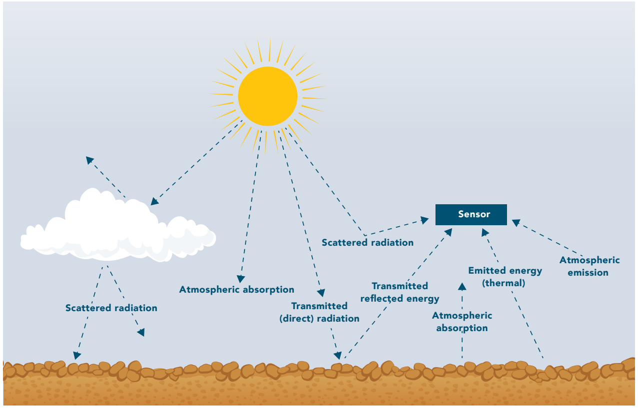
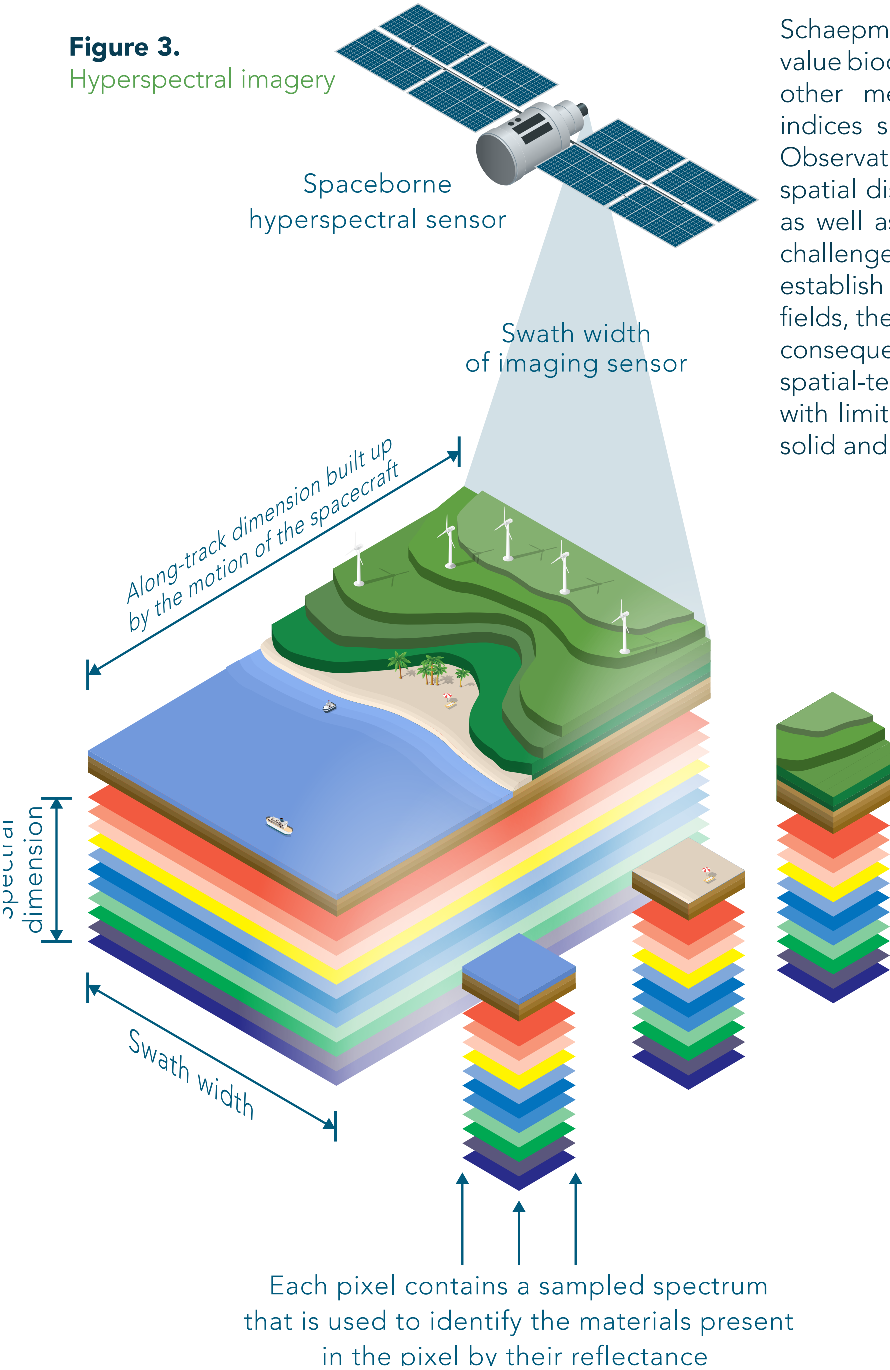
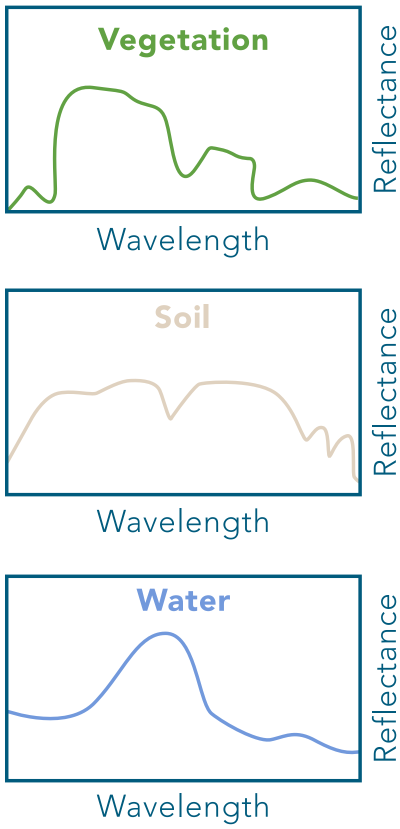


Figure 2. Energy interaction in atmosphere & surface

Schaepman et al. 2007 states that ecologists mainly value biodiversity in terms of species richness amongst other metrics as well as using various diversity indices such at the Shannon index, whereas Earth Observation based instruments usually measure the spatial distribution of radiance fields, backscattering, as well as polarization state changes. It is the main challenge of Earth Observation and Ecology to establish semantic interoperability between these two fields, then establish common sampling schemes, and consequently bridge scaling gaps finally allowing a spatial-temporal continuous sampling of biodiversity with limited discontinuities. This in combination with solid and continuous ground observations.

Figure 3. Hyperspectral imagery





REMOTE SENSING DATA SOURCES

More and more satellite imagery becomes freely and easily accessible. Good examples of these are the USA Landsat programme and the European Copernicus programme with the Sentinels 1-5 with their specific application domains, next to commercial satellite information at very high resolutions (around 1 meter resolution). A great advantage is also that large archives exist with historical data which makes the assessment of changes more convenient.

Since, amongst others, Sentinel-2 satellite imagery is freely available at high spatial and temporal resolution, we can collect times series for various periods of time.

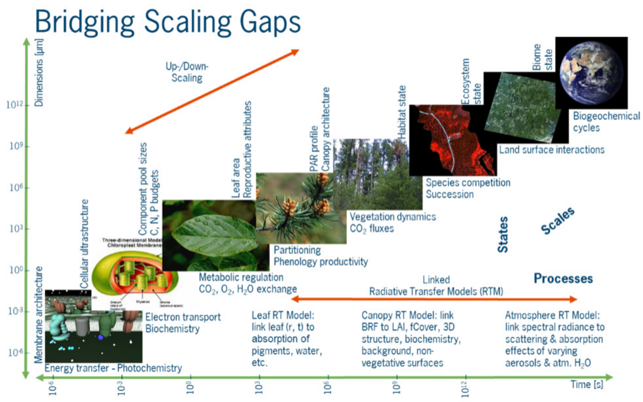


Figure 4. Scaling of states and processes from the cell scale to global scales (Schaepman et al, 2007; Modified after John Miller).

Satellite sensor	Launch	Number & Types	Spatial resolution [m]	Revisit time (days)	Examples products
Landsat-8	2013	11 (VNIR,SWIR,TIR)	15 (pan), 30m (ms), 100m (TIR)	16	Reflection, NDVI, LAI, temperature, and thematic classifications
Aster	1999	3, 6, 5 (VNIR,SWIR,TIR)	15 (VNIR), 30 (SWIR) 90 (TIR)		Reflection, NDVI, LAI, temperature, and thematic classifications
RapidEye (5 satelliet constellatie)	2008	5 (B,G,R,NIR, RedEdge)	5 (ms)	1	Reflection, NDVI, LAI, chlorofyl / N concentration and thematic classifications
SPOT-6 & 7	2012/2014	4 (B,G,R,NIR)	1.5 (pan) 8 (ms)	1	Reflection, NDVI, LAI, temperature, and thematic classifications
Sentinel-2A & B (2 satelliet constellatie)	2015/2016	13 (VNIR, NIR, SWIR)	10, 20, 60	< 5	Reflection, NDVI, LAI, chlorofyl / N concentration, and thematic classifications
Sentinel-1	2015	2 (VH, VV)	10	6	Height, soil moisture, biomass, phenology, land cover
Ikonos	1999	4 (B,G,R,NIR)	1 (pan) 4 (ms)		Reflection, NDVI, LAI, and thematic classifications
QuickBird	2001	4 (B,G,R,NIR)	0.65 (pan) 2.6 (ms)	1 - 3.5	Reflection, NDVI, LAI Classification
GeoEye-1	2008	4 (B,G,R,NIR)	0.4 (pan)	~3	Reflection, NDVI, LAI
GeoEye-2 (WorldView-4)	2016		0.3 (pan) 1.2 (ms)	<3	Reflection, NDVI, LAI, chlorofyl / N concentration Classification
SkySat-1 & 2	2013/2014	4 (B,G,R,NIR)	0.9 (pan) 2 (ms)		Reflection, NDVI, LAI, and thematic classifications
Pleiades-1A & B (2 satelliet constellatie)	2011/2012	4 (B,G,R,NIR)	0.5 (pan) 2 (ms)	1	Reflection, NDVI, LAI and thematic classifications Classification
WorldView-3	2014	8(B,G,R,coastal, yellow,NIR, RedEdge,NIR2) 8 SWIR 12 CAVIS	0.31 (pan) 1.24 (ms) 3.7 (short wave IR)	<1	Reflectiion, NDVI, LAI, chlorofyl / N concentration Classification

Box 1. Overview of common satellite sensors and their main characteristics. Note PAN means panchromatic (B&W), MS means multi-spectral, VNIR means Visible and Near Infra-Red, and SWIR means Shortwave Infrared. NDVI: Normalized Difference Vegetation Index, LAI: Leaf Area Index.

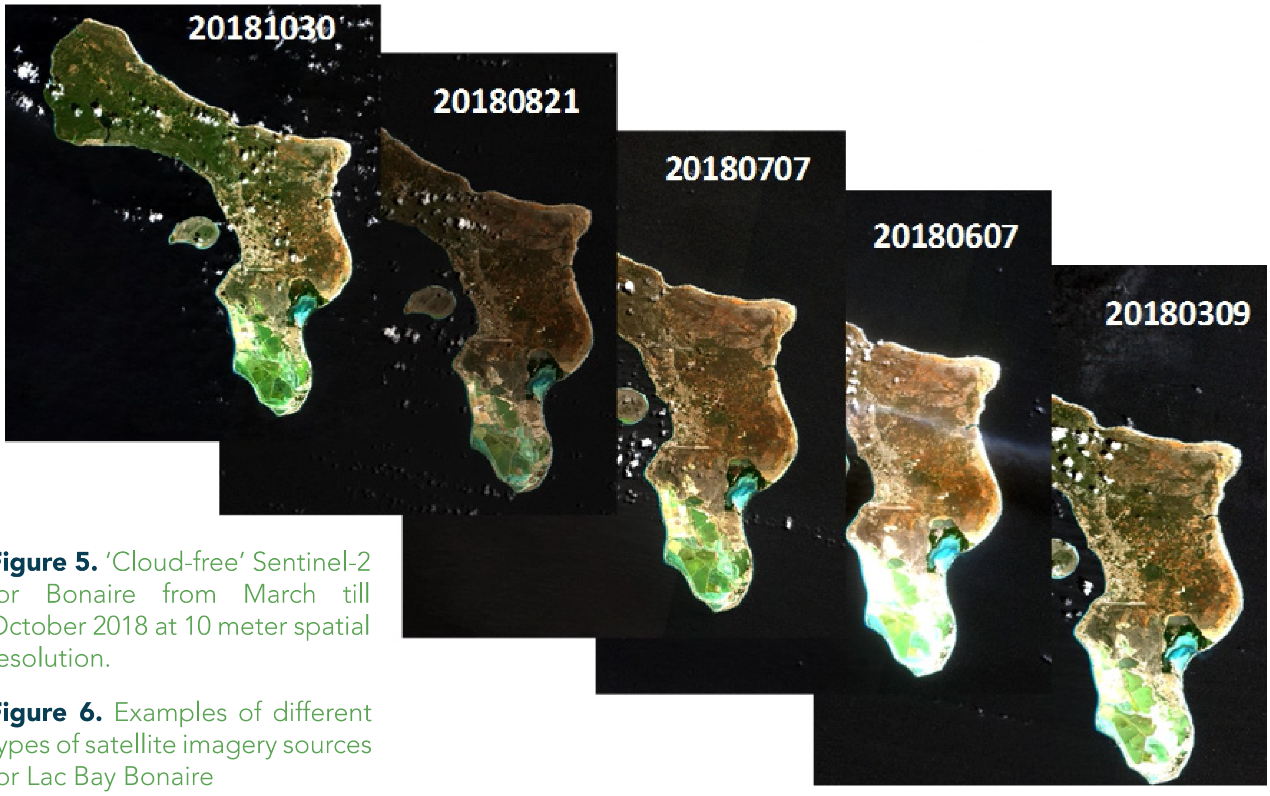


Figure 5. 'Cloud-free' Sentinel-2 for Bonaire from March till October 2018 at 10 meter spatial resolution.

Figure 6. Examples of different types of satellite imagery sources for Lac Bay Bonaire

Landsat-5 27th of December 1984. 30 m pixels

Landsat-5 24th of September 2014. 30 m pixels

Sentinel 2A 14th of April 2016. 10 m pixels

Same Sentinel 2A 14th of April 2016. 10 m pixels. But more zoomed in.

Pleiades 28th of February 2014 2m pixels.

Same Pleiades 28th of February 2014 2m pixels. But more zoomed in.

EXAMPLES OF THE USE OF REMOTE SENSING TOOLS

Sea Level Rise and coastlines

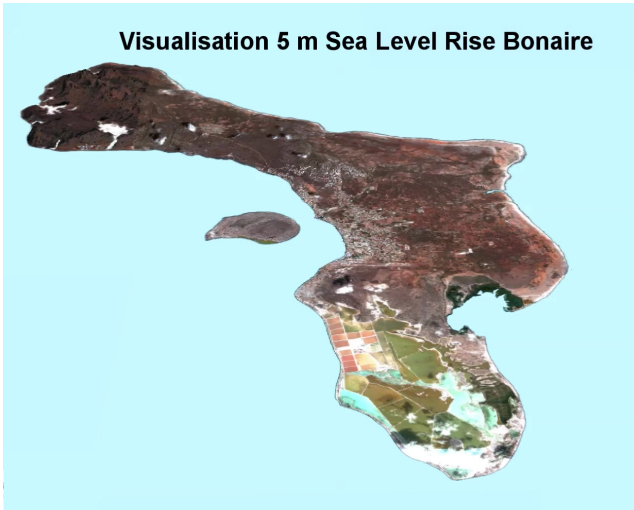
The most recent climate change predictions for the Caribbean region (2013/2014) by the Intergovernmental Panel on Climate Change (IPCC) are alarming and suggest that the islands of the Dutch Caribbean will go through profound environmental changes within the next century (DCNA, 2016). Under the intermediate low-emissions scenario, the IPCC has projected a sea level rise of 0.5 to 0.6 m for the Caribbean Region by the end of this century. What does this mean for Bonaire?

Figure 7. Simulating impact sea level rise for Bonaire using a Digital Elevation Model (DEM).

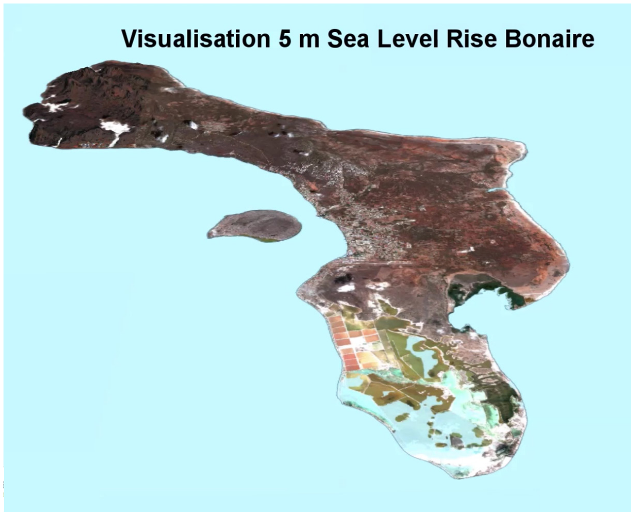
Based on Aster satellite imagery derived Digital Elevation Model, we can model the impact for Bonaire of different levels of sea rise.

It is clear that southern part of Bonaire is very sensitive for any sea level rise (SLR). The exact impact of the SLR will of course also depend on the spatial details and accuracy of the digital elevation model that is used. In the figure above it is clear that many of the beaches will disappear where turtles lay their eggs in the breeding season.

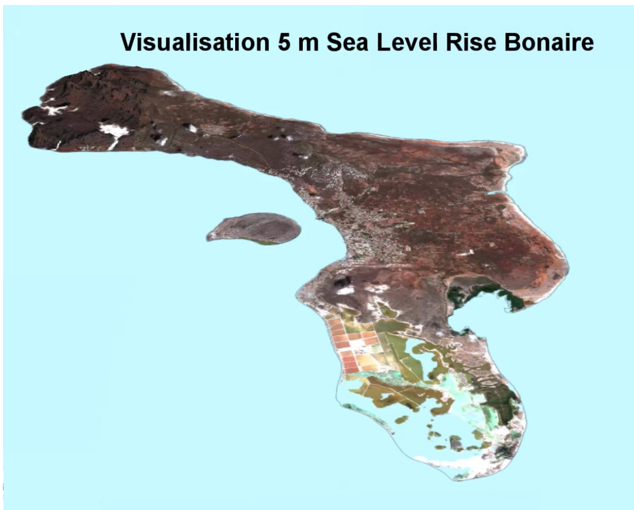
For this and other reasons, it is also important to monitor the coastal erosion. Sentinel-1 RADAR is well equipped for coastline detection and can as such be used to detect changes in coastlines. Below is an example of coastline detection based on Sentinel-1 imagery for 2015 and 2018. However, the coastline methodology should be based on much more Sentinel-1 imagery to avoid change effects due to changes in sea tides. The effect of sea tides are not completely removed in the example given below.



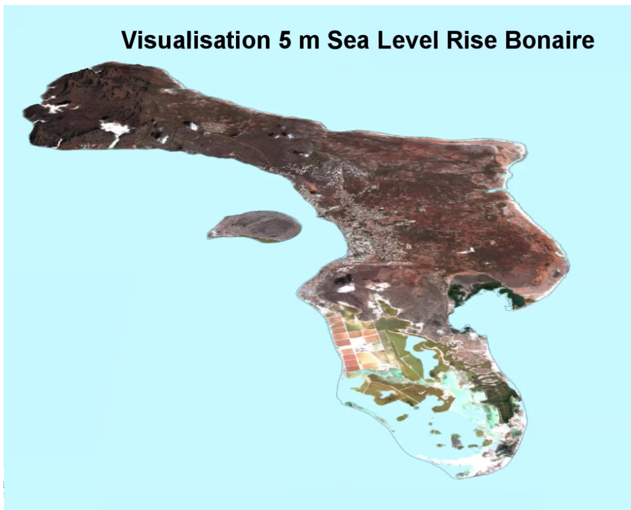
Sea Level Rise: 0 m



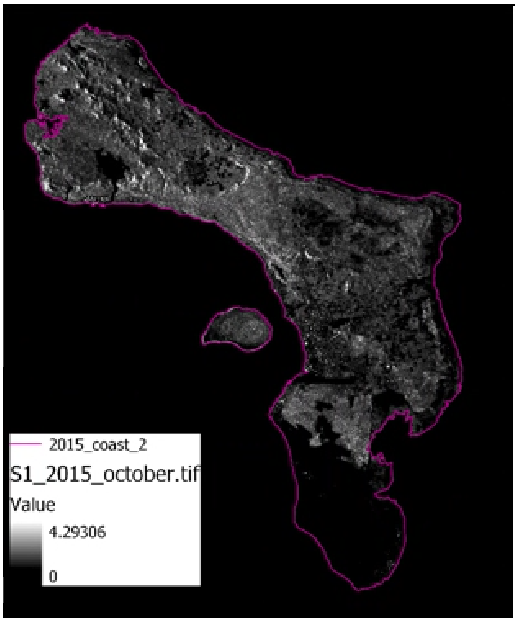
Sea Level Rise: 0.5 m



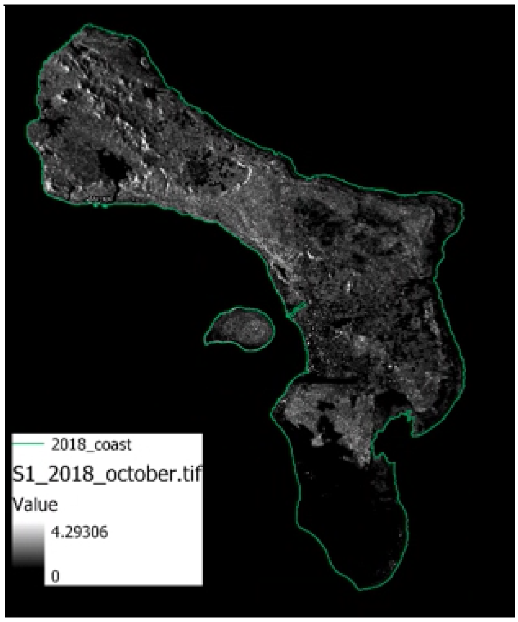
Sea Level Rise: 2 m



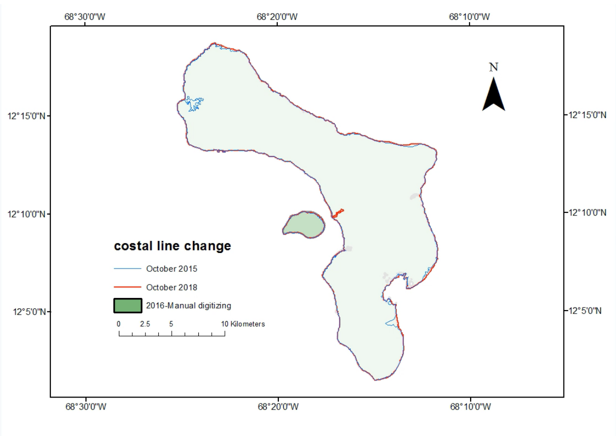
Sea Level Rise: 1 m



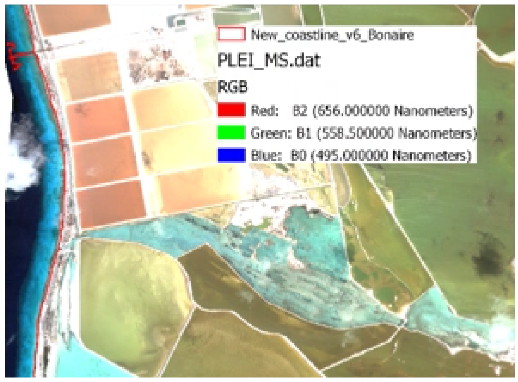
Coastline detection based on Sentinel-1 RADAR Image of October 2015



Coastline detection based on Sentinel-1 RADAR Image of October 2018



Changes in coastline 2015 - 2018
(Not yet corrected for differences is sea total levels)



Detail of the coastline shown on Pleiades Image of 2016

Figure 8. Coastline detection and detection of coastal erosion using RADAR and optical satellite data

Coral reef mapping using hyperspectral imagery

The importance of coral reefs is multifunctional and provides ecosystem services not only to attract tourism and therefore income, but also as a natural barrier to protect the coast, and as a habitat for many species, providing food as well. The general consensus is that the extent and biodiversity of Bonaire's coral reef is decreasing due to local and regional anthropogenic and global climate pressures. However, the last extensive study of the coral coverage of the reef ecosystem was performed in 1985 by Van Duyl who created an underwater atlas of Bonaire and Curaçao. In order to update this atlas of Bonaire's coral reefs, a hyperspectral mapping campaign was performed in October 2013 using the Wageningen UR Hyperspectral Mapping System (HYMSY) with 101 spectral channels. The HYMSY camera consists of a custom pushbroom spectrometer (range 450–950nm, FWHM 9nm, ~20 lines/s, 328 pixels/line), a consumer camera (collecting 16MPix raw image every 2 seconds), a GPS-Inertia Navigation System (GPS-INS), and synchronization and data storage units. The weight of the system at take-off is 2.0kg allowing it to be mounted on varying platforms (Mucher et al., 2017).

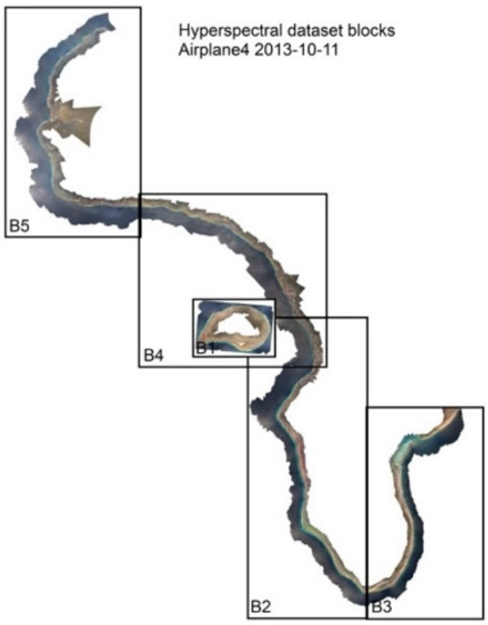


Figure 9. The hyperspectral data were recorded on 11th October 2013 by the HYMSY camera mounted on a Cessna airplane and were mosaicked and georeferenced to form a hyperspectral image of the coastline of Bonaire. Data were processed in 5 hyperspectral dataset blocks (Mücher et al., 2017).

In order to interpret the data more consistently, the hyperspectral data were corrected for the water depth into at-ground-reflectance factor units. A bathymetric (sea bottom) model was used for the calibration of the hyperspectral imagery based on a former field campaign by measuring water depth at specific locations along the western coast. The final bathymetric model that we used was based on extrapolation of the terrestrial digital elevation model through fitting with additional in-situ bathymetric measurements on sea. A better bathymetric model would of course have been preferred to calibrate the hyperspectral data with a 1 meter spatial resolution more accurately (Mucher et al., 2017).

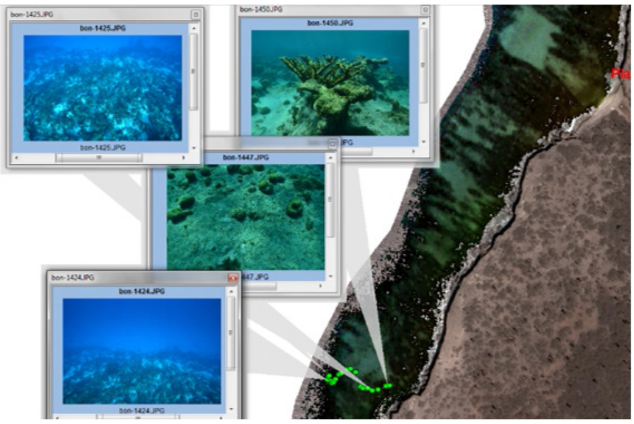


Figure 10. HYMSY hyperspectral spectral imagery (RGB: 520 nm, 480 nm, 476 nm) with green dots showing the most northern diving transect. Image (mainly the land section) behind the hyperspectral image is a Pleiades satellite image (brown to greyish colours) with 50 cm resolution (Mucher et al, 2017).

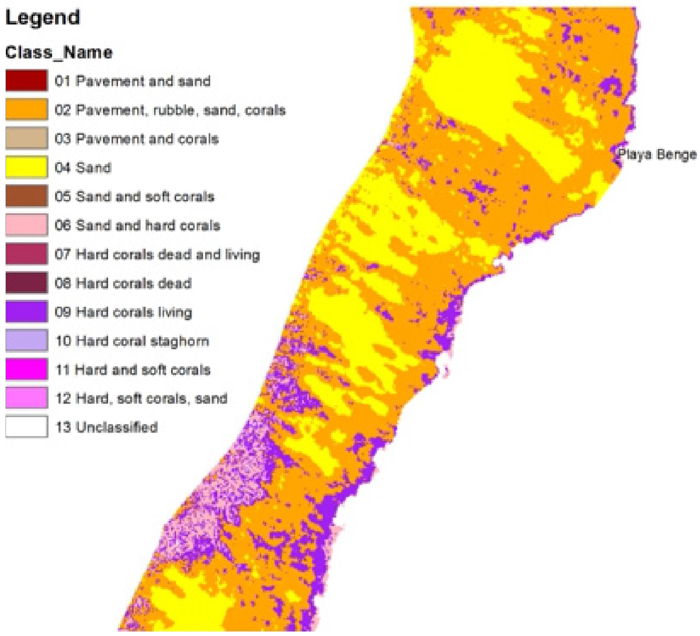


Figure 11. Detail of the Hyperspectral Coral Reef Classification (HCRC) near Playa Benge on the Northern coast of Bonaire (Mucher et al., 2017).

Catchments and erosion hazards

Past deforestation, overgrazing and urbanization have led to an increase in surface runoff and erosion in amongst others the Playa catchment, Bonaire. Together with the lack of sufficient spatial planning, this has led to increased flooding and larger sediment flows into the ocean causing harm to the island's famous coral reefs (Koster, 2013). The study of Koster (2013) concentrated only on a selected part of the island. Remote sensing and associated sciences with respect to soil erosion can provide relevant information for the entire island, to inform decision makers in a better way. The simplest way to calculate soil loss is to use the Universal Soil Loss (USL) Equation used to estimate average annual soil loss caused by sheet and rill erosion. The equation is limited for making predictions for long-term annual soil loss only compared to making predictions on single rainfall event. The USLE Equation is: A = R * K * LS * C * P, where, A = predicted soil loss (tons per acre per year), R = rainfall and runoff factor, K = soil erodibility factor, LS = slope factor (length and steepness); C = crop and cover management factor; P = conservation practice factor interesting is to find out where surface runoff and erosion reaches the coast and threats the coral reefs.

But first of all, a catchment classification has to be made of the entire island, to enable such a study. For mapping these catchments, remote sensing is very useful. In addition, a Digital Elevation Model (DEM) with a very high resolution and accurate height measurements are a prerequisite. Since the required remotely sensed DEM data were at this stage not freely available, we used in this preliminary study the ASTER DEM to demonstrate the potential value of this remote sensing application for policy making and environmental management.

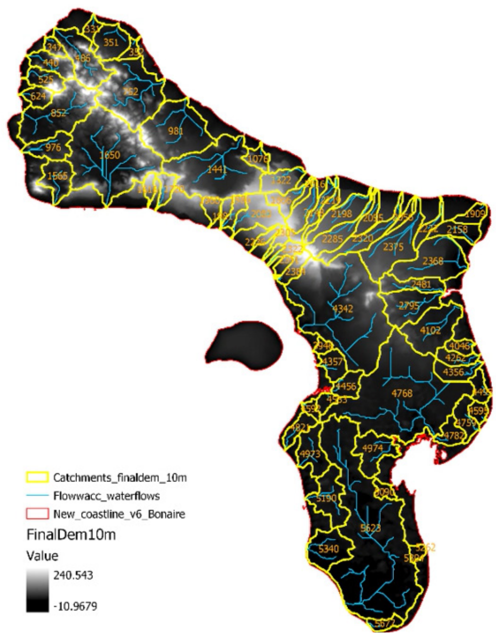


Figure 12. Catchment classification with potential water flows made with ARCGIS hydrology tools using the ASTER DEM as an input.

A preliminary erosion hazard map for Bonaire was made based on calculating the vegetation fraction (at moments with maximum vegetation cover) based on Sentinel-2 imagery and derivation of slope and length based on ASTER DEM. The example below shows the erosion hazard for those catchment that are completely or partly covered with agriculture-Konuku.

It shows that most of the catchments with agriculture-Konuku have potentials of serious erosion hazards with the risk that sediments will reach the coastal waters. Specific measures should be taken to avoid such an impact.

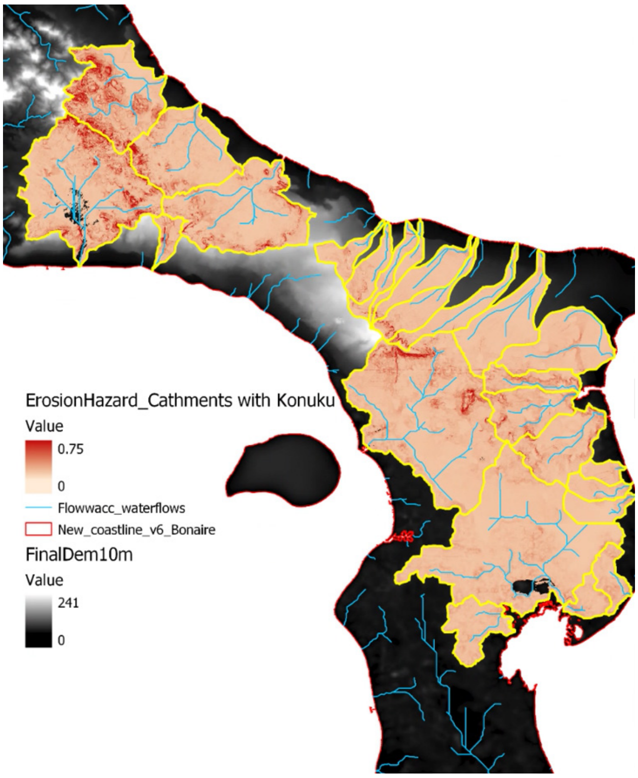
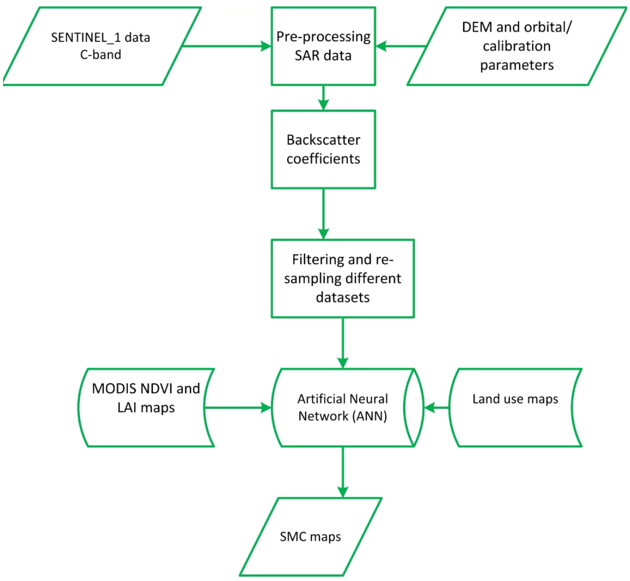


Figure 13. A preliminary erosion hazard map for Bonaire for those catchment that are completely or partly covered with agriculture-Konuku.

Soil moisture

Information on surface soil moisture is especially important in relation to agriculture. Soil moisture maps can be derived from RADAR satellite data, and the example below is showing so for SENTINEL-1 Synthetic Aperture Radar (SAR) instrument of which the acquired data is freely available. The figure below shows the workflow to produce such soil moisture map by SAR (Sentinel-1) data.

The moisture content is scaled between 0 (0% moisture) and 1 (100% moist). Next to the value of such soil moisture maps, we should also notice that very specific flat surfaces such as asphalt or salty soils also appear as very moist pixels, and should be corrected for.



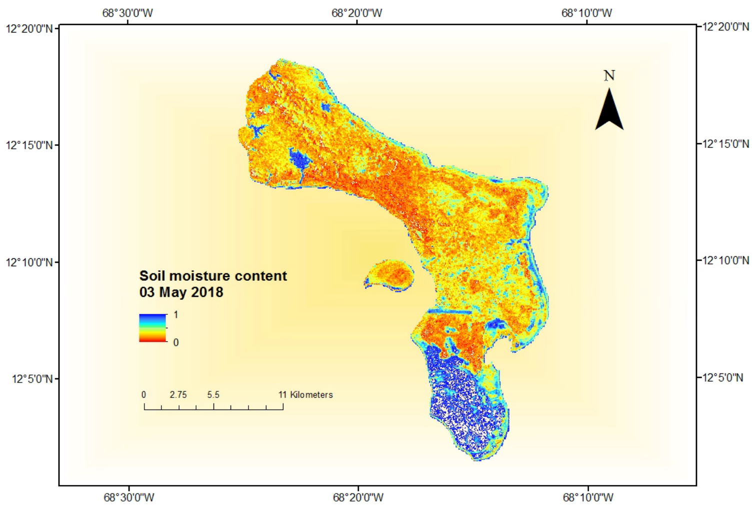


Figure 14. The workflow of producing soil moisture map by SAR (Sentinel-1) data and the resulting soil moisture map for one specific day, namely 3rd of May 2018.

Land cover mapping and monitoring

Land cover mapping and monitoring is one of the longest existing application domains in remote sensing that exists for more than a century (accounting for use of aerial imagery as well). The land cover information is often used as an input for running other models, but also as an input for spatial planning, environmental monitoring and decision making (Mücher et al, 2000; Clevers et al., 2007; Gerard et al., 2010; Feranec et al., 2010; Smith et al., 2013; Mücher et al., 2015; Hazeu 2014). The satellite sources used for land cover mapping concern mostly multi-spectral imagery acquired at specific seasons of the year. A multi-temporal approach is for example needed to distinguish bare ground from agriculture, or to distinguish wheat field from a grassland patch. Historical satellite archives make it possible to produce time series and look at specific land cover changes. Nowadays many land cover maps have a spatial resolution between 25-10 meter resolution and are regular being updated. The example below shows a preliminary land cover classification based on a Pleiades image of March 2016 for the area around Rincon. The second example shows that time series of satellite imagery can indicate when a certain land use or land cover change has taken place.

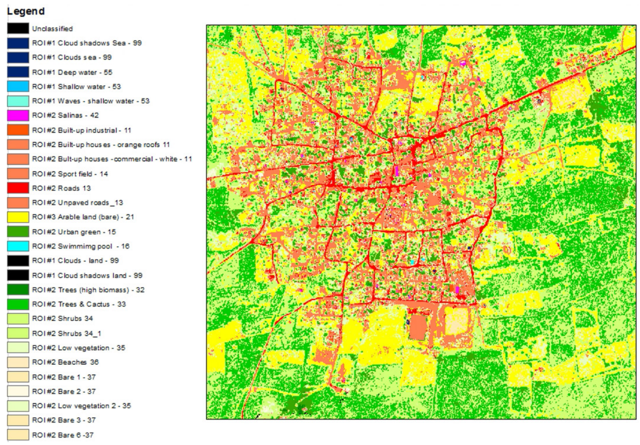


Figure 15. A example of a preliminary land cover classification based on a Pleiades image of March 2016 for the area around Rincon.

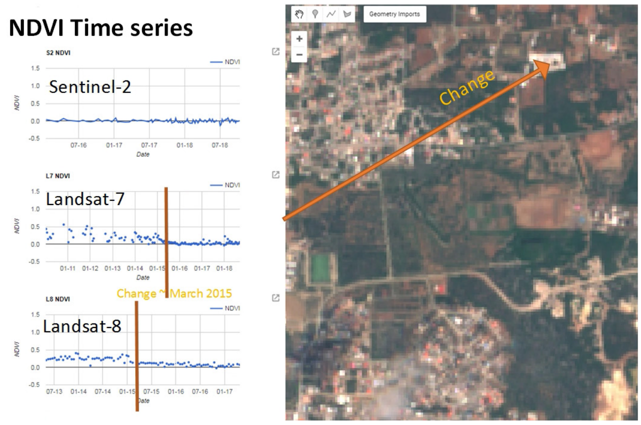


Figure 16. Time series of satellite imagery makes it possible to indicate the timing of the change. This example shows that new construction in suburb (pointed by orange arrow) Kralendijk started in March 2015 based on Landsat 7 and Landsat 8. Sentinel-2 is only available since July 2015 and shows no change in biomass at all (so showing that the construction is there).

WAY FORWARD & FUTURE WORK

The examples above are just a few examples of the way that remote sensing can provide basic surveying information and can support environmental monitoring for decision making. Also on specific events such as the amount of Sargassum that washed in March 2018 on the beaches of Bonaire could be surveyed in coastal regions and on sea using airborne or spaceborne imagery. Satellite imagery can provide synoptic information at appropriate spatial and temporal resolutions that can support evidence based monitoring that can provide policy makers, conservation managers, entrepeneurs, scientists and the general public with information on the state, pressures and associated changes in the environment. At the same time much work has to be done to bring such information in the proper format to those people on the islands that need such information and can translate it towards decision making. Only in such a way shared fact finding will work. Moreover, the more local information is added to the interpretation of the satellite imagery the better the results are.

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