Nexus interventions for small tropical islands: case study Bonaire

Ecosystem

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

WAGENINGEN UNIVERSITY & RESEARCH

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

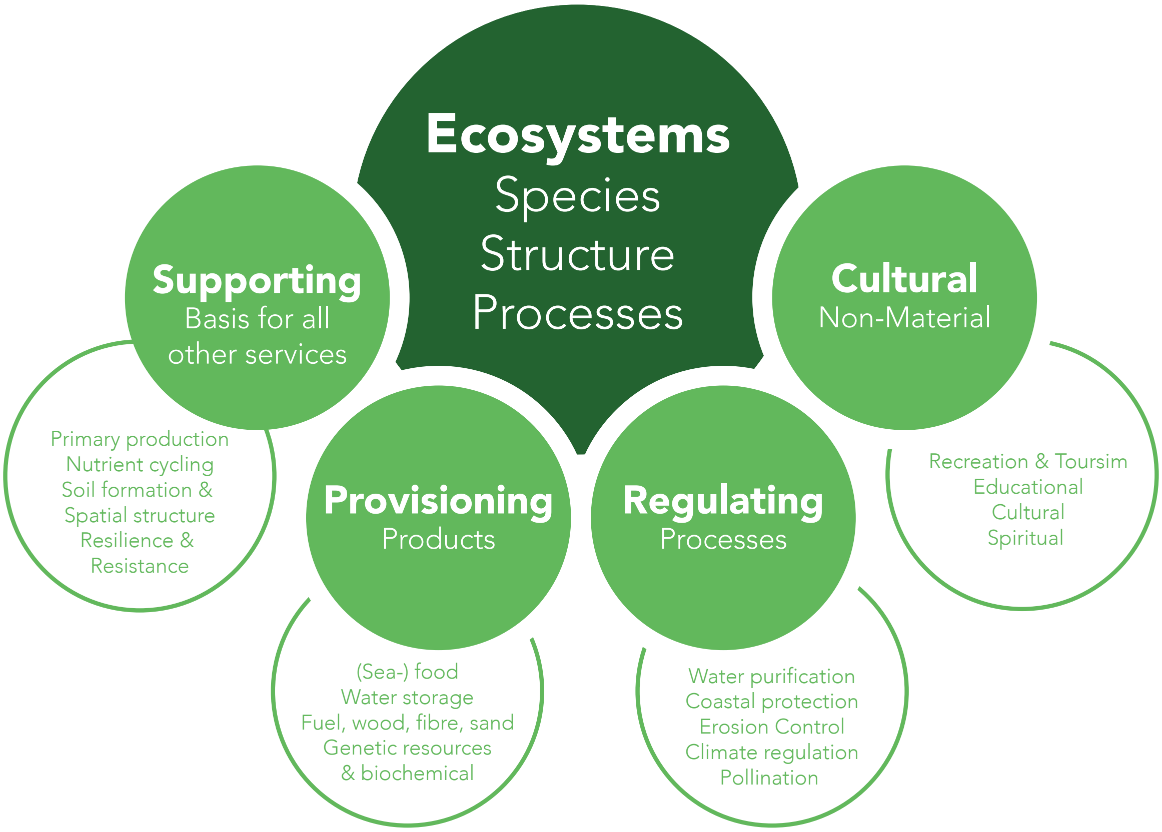


Figure 1. Overview of ecosystem services relevant for SIDS

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.

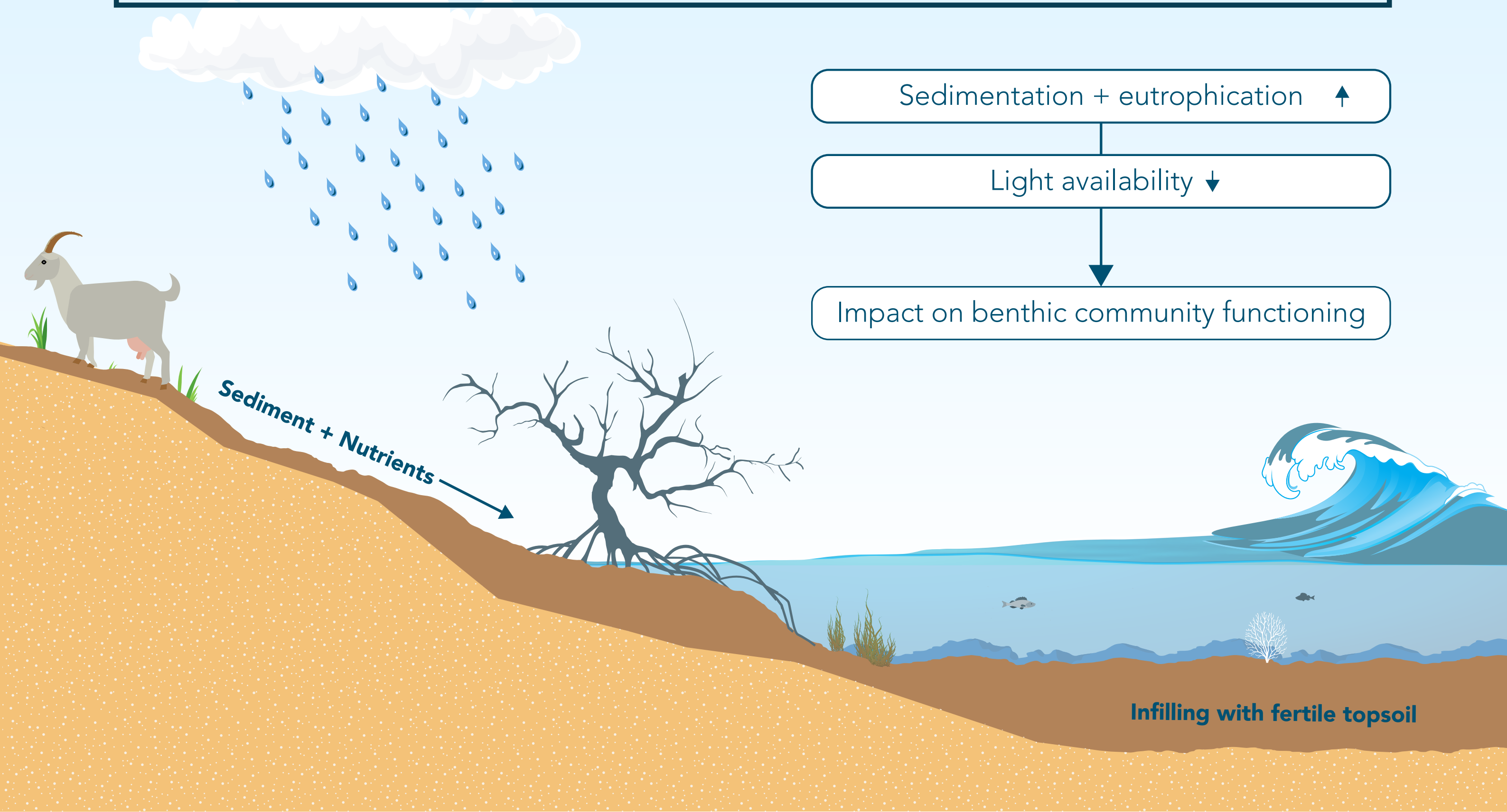
Information on ecosystem components, and the magnitude of the drivers of change, are needed in order to effectively manage and protect the ecosystem's intrinsic value and the benefits it provides to people. However, for Bonaire only very limited structural monitoring of habitats and species occurs, which 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.

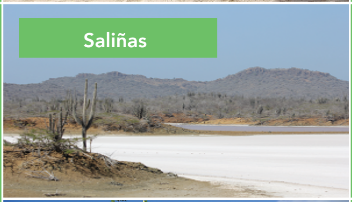
Bonaire, as part of the Netherlands, has to comply with several national and international policy frameworks, treaties and conventions (see generic factsheet). On the national level, the Nature Policy Plan Caribbean Netherlands (2013-2017) aims to ensure that nature on the islands is used in a sustainable 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.

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

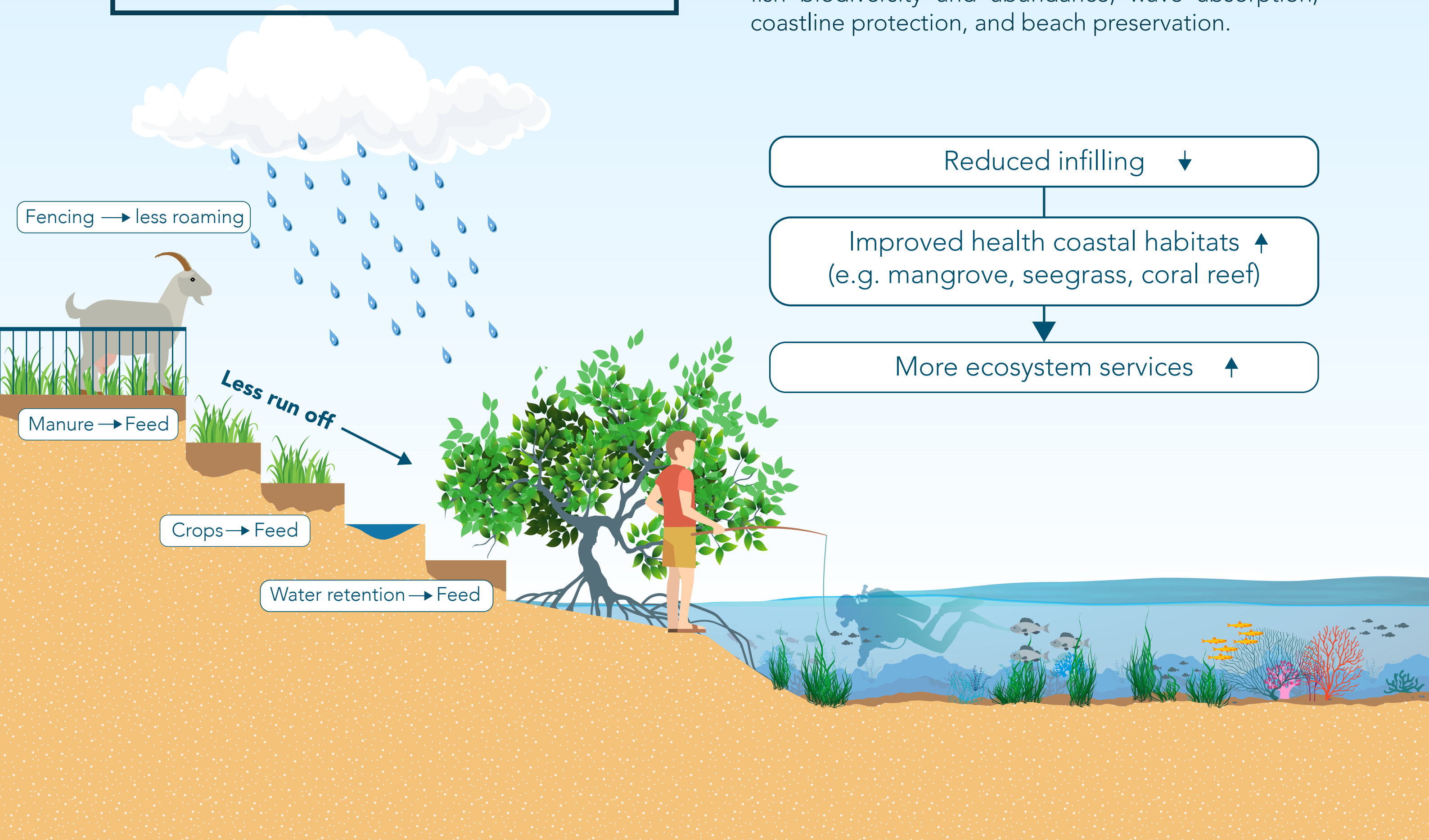
Building with Nature / Nature inclusive building

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.

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.



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

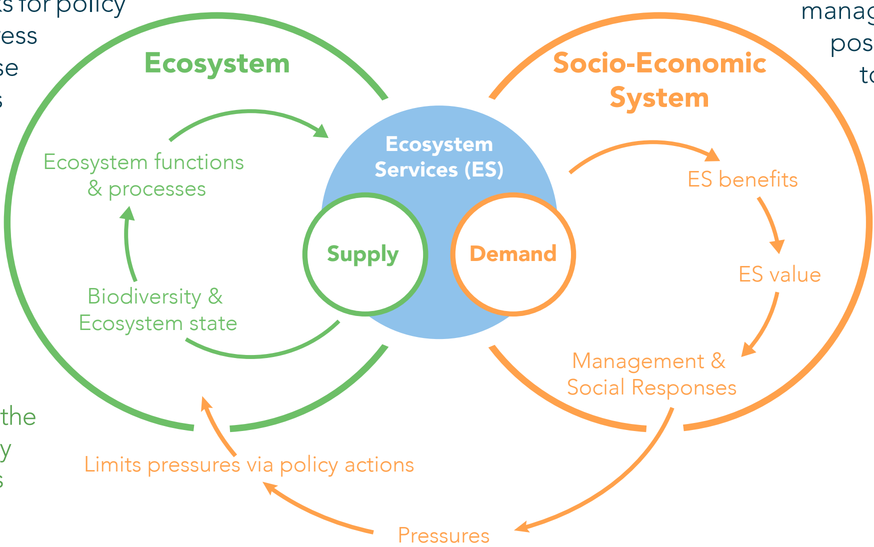


Figure 4. Representation of Social-ecological Systems highlighting the flows from biodiversity to ecosystem services (figure modified after Gómez et al. (2016)

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.

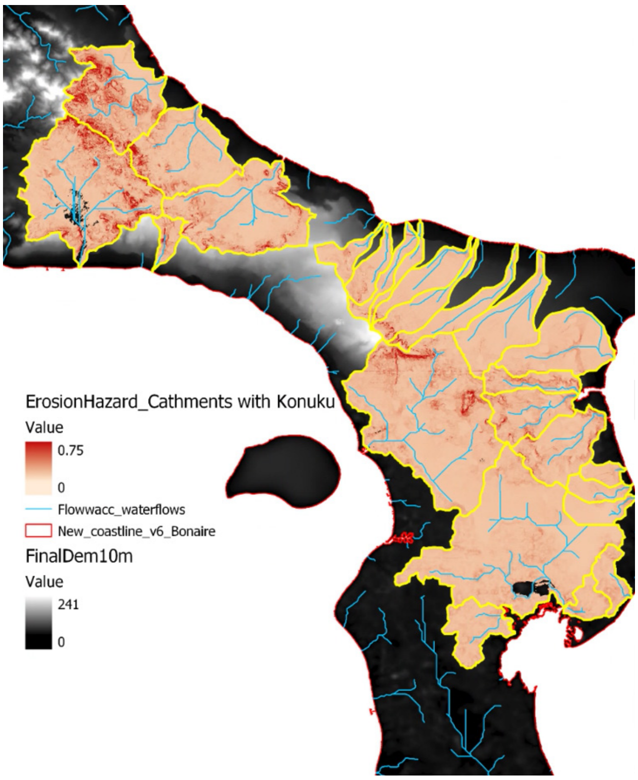


Figure 5. A preliminary erosion hazard map for Bonaire for those catchment areas that are completely or partly covered with agricultural corp / Kunuku

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 UNIVERSITY & RESEARCH

Authors: Diana Slijkerman, Dolfi Debrot,
René Henkens, Matthijs van der Geest
& Sander Mücher

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