IVM Institute for Environmental Studies

Student essays on economic values of nature of Bonaire

A desk study

Editors

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Contents

Summary

To inform decision makers about the most effective strategies to protect the ecosystems of Bonaire, a full-scale valuation of all ecosystem services on the island of Bonaire has been undertaken by WIKCS and the VU University Amsterdam. The study addresses a wide range of ecosystems, ecosystem services and applies a multitude of economic valuation and evaluation tools. For budgetary reasons, a distinction has been made in terms of the ecosystem services covered by the studies between ecosystem services that are valued through primary research and ecosystems services that are addressed through secondary data analysis. This report summarises the ecosystem services that are valued on the basis of desk research or through key informant interviews. The quality of each sub-study varies, depending on the data availability to the subsequent researchers. This also implies that not each sub-study was able to actually generate a monetary value to be included in the Total Economic Value (TEV) estimate. Despite this caveat, the individual studies increase the understanding of the complex links between nature and society on Bonaire and are therefore worth presenting.

Art value

Artists are inspired by their surroundings. Such is also the case on Bonaire, where the natural scenery of the island stimulates artists to use components of nature in their work. Clearly, nature plays a crucial role in the production process of art on Bonaire. The demand of art consists of the thousands and thousands of tourists visiting the island, who are keen to bring home a piece of art to memorise the beauty of the island upon their return. Moreover, the beautiful photographs and books produced on Bonaire are distributed to clients across the world. Given the explicit demand and supply of art on Bonaire and its strong dependence on nature, the art sector on Bonaire plays an important role in the overall economy and provides an additional reason to manage nature well on the island. The value of the ecosystem service of artistic inspiration is valued at $460,000 annually.

Research value

Nature in Bonaire provides important services for research and education. The marine and terrestrial environment of Bonaire is subject for a large group of academics who conduct and publish innovative research based on these unique and easily accessible ecosystems. Without the presence of healthy ecosystems, Bonaire would not attract large numbers of researchers nor would Bonaire's nature be a source of inspiration for many educational activities on the island and beyond. This sub-study made an inventory of all ecosystem related research expenditures funded by governmental and non-governmental organisations for Bonaire. In total a total research value was estimated between 1,240,000 USD and 1,485,000 USD in 2011.

Medical and pharmaceutical value

Medicinal plants play important roles in many traditional societies. The healing properties of herbal medicines have been recognized in many ancient cultures thousands of years ago. Besides these local benefits, biodiversity is important for the development of pharmaceutical treatments and drugs. The purpose of this sub-study is to economically value the benefits of species and ecosystem functions that are relevant

for medicinal and pharmaceutical purposes. The study found that a large part of the population in Bonaire regularly collects and uses local herbs and other medicinal plants for medical treatment. Two-third of the inhabitants who were surveyed made use of local plants as an alternative to modern medicine or prescription drugs. Ultimately, a total annual medicinal and pharmaceutical value results of $688,788 of which more than half is comprised of the local value of medicinal plants.

Carbon sequestration

The ecosystem service of climate regulation deals mainly with greenhouse gas emissions and how ecosystems can mitigate such effects. Bonaire has six ecosystems that provide carbon-sequestering properties: salinas, dry forest, coral reefs, sea grass, mangroves and open ocean. The objectives of this sub-study is to (1) identify the ecosystems that are relevant to climate regulation in Bonaire with their functions and threats; (2) describe the different economic valuation methods suitable for climate regulation calculations; and (3) value the overall climate regulation potential of Bonaire. This desk study has made a rough attempt to estimate the carbon sequestration value of the main ecosystems of Bonaire. Based on carbon market prices at the time of research, this value was estimated at $290,000 per year.

Pollination by bats

The island of Bonaire is a fauna and flora rich and beautiful attraction in the Caribbean. By supporting fruit growth and aesthetic values, bats plays an important role in preserving high levels of biodiversity on Bonaire. This study made an attempt to give more insight in the importance pollination by bats for the island. Due to limited availability of data and time, the study will not generate an actual economic value of pollination. Yet, by describing the possible links between pollination and the economy of Bonaire, this study adds value and provides a solid foundation for an actual economic valuation study in the future. Despite of the lack of a concrete economic value, the evidence provide support the notion of conservation of the bats of Bonaire their natural habitat (i.e. caves). Both economic and cultural reasons have been identified to support this conclusion.

Coastal water quality

This paper attempts to examine the values of ecosystems in provisioning good water quality in Bonaire, Dutch Antilles. Bateman's (2011) steps in ecosystem assessment and economic analysis are used as a framework to run this examination. Three ecosystems are identified that contributes to deliver services in question: mangroves, saliñas/salt marshes, and sea grasses. Based on their functions related to providing good water quality (filtering, water purification, and nutrient cycling) this report proposes three valuation methods: 1) replacement cost method for mangroves and saliñas; 2) Production function method for sea grasses. Benefit transfer also mentioned in the discourse to tackle the challenge of finding relevant data.

Amenity value

The fact that many people prefer natural over built environments is often manifested in house prices. Therefore various environmental conditions may have a significant impact on house prices. In Bonaire these include the view or proximity to water bodies, coral reefs and other healthy ecosystems. This study aims to estimate this so-called amenity value of nature on Bonaire. Through a hedonic pricing analysis, the hypothesis was tested whether property values are not only determined by conventional house and neighbourhood characteristics, but also affected by the presence and quality of Bonaire's ecosystems. From this statistical analysis no strong significant impact of environmental variables onto the house prices has been detected and thus the hypothesis is rejected. This lack of evidence limits the possibility to calculate the amenity value. The cause of the poorly performing analysis is the limited data available on house sales on Bonaire.

Cultural value

The island of Bonaire has a precious though threatened nature and its culture is indistinguishable from nature. Yet, times are changing and so is the relationship between nature and society in Bonaire. Since the development of industrial times, less Bonairean practise agriculture, and less people are working in the nature. The objective of this study is to estimate the value of the cultural ecosystem services of the island of Bonaire. The scope of this sub-study is limited to four cultural values of ecosystems on Bonaire: (1) Recreational activities; (2) Subsistence and recreational fishing; (3) Kunukus; and (4) Cultural landscape.

Ecological footprint

Cruise ships bring well paying tourist to Bonaire but at the same also cause negative environmental impacts to the fragile ecosystems of Bonaire. The model 'Acquatrail' has been applied to get a better understanding of the actual environmental impact caused by cruise ship tourism. Acquatrail is the aquatic equivalent of the carbon footprint in the sense that it takes water pollutants into consideration, i.e. gaseous, liquids and solids that damage aquatic environments. By contributing alongside carbon and water footprints it provides a holistic picture of anthropogenic impacts on marine environments. The total external cost that cruise ships entering the Bonaire harbour impose on the environment in 2011 is estimated at around US$100,000.

Acknowledgements

These essays would not have been possible without the enormous support of numerous people and organisations on Bonaire. First of all, we want to thank ministry of Economic Affairs, Agriculture and Innovation Caribbean Netherlands, especially Hayo Haanstra, Astrid Hilgers, Ruth Schipper-Tops and Pieter van Baren for making this research possible in the first place and special thanks to Paul Hoetjes, for facilitating the study and for helping us overcome hurdles that we encountered during the course of the study. Additionally, I would like to thank the commissioners of the Island Territory Bonaire and island secretary N. Gonzalez and the Directorate of Spatial Planning and Development, Unit Nature and Environment, especially Frank van Slobbe for his valuable input and for introducing us to the right people, and STINAPA, especially Ramon de Leon and Fernando Simal for discussing the study and giving valuable feedback. Other people that helped us are Kris Kats and Jan Jaap van Almenkerk liaison with and Jozef van Brussel work at the ministry of Infrastructure & Environment the Netherland and special thanks to Danilo Christiaan.

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1 Introduction

Bonaire is a small, tropical island located in the Caribbean Sea just north of Venezuela. The ecosystems of Bonaire (especially the coral reefs) are some of the most pristine in the world, attracting more than 200,000 tourists per year and significantly contributing to Bonaire's economy (IUCN 2011; Stat Yearbook 2010). Recently, scientific studies have reported declines in ecosystem health attributed to anthropogenic activities on the island (Slijkerman *et al.*, 2011). This is of serious concern because of the direct uses for which locals utilize these resources and the significant role that tourism plays on the island.

To inform decision makers about the most effective strategies to protect these important ecosystems, a full-scale valuation of all ecosystem services on the island of Bonaire has been undertaken by WKICS and the VU University Amsterdam. As shown in Figure 1.1, the study addresses a wide range of ecosystems, ecosystem services and applies a multitude of economic valuation and evaluation tools. For budgetary reasons, a distinction has been made in terms of the ecosystem services covered by the studies between ecosystem services that are valued through primary research and ecosystems services that are addressed through secondary data analysis (see second column in Figure 1.1.

The primary studies are published in separate reports. Local recreational and cultural values are reported in Laclé *et al.* 2011. The non-use values of nature in Bonaire and other Netherland Caribbean islands are presented in van Beukering *et al.* 2012. The coastal protection value of coral reefs in Bonaire is valued in van Zanten *et al.* 2012 and the fisheries benefits of marine ecosystems are estimated in Schep *et al.* 2012a. The ecosystem service of tourism is reported in Schep *et al.* 2012b.

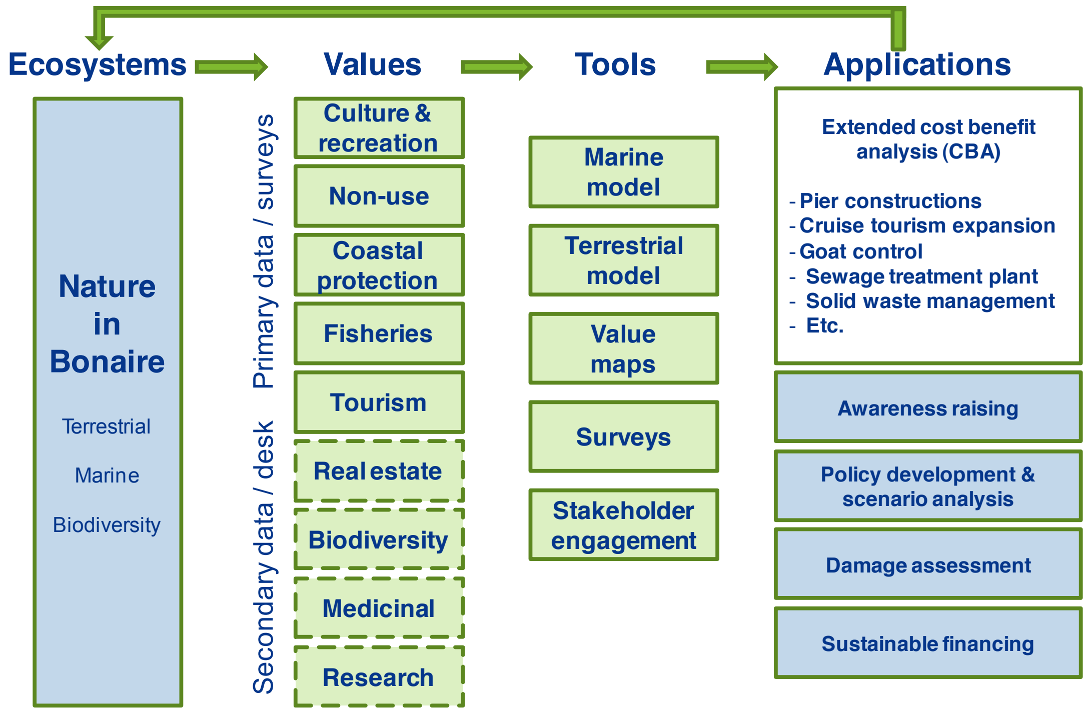


Figure 1.1 Conceptual framework of the TEEB-Bonaire study

This report summarises the ecosystem services that are valued on the basis of desk research or through key informant interviews. The quality of each sub-study varies, depending on the data availability to the subsequent researchers. This also implies that not each sub-study was able to actually generate a monetary value to be included in the Total Economic Value (TEV) estimate. Despite this caveat, the individual studies increase the understanding of the complex links between nature and society on Bonaire and are therefore worth presenting.[1]

Because the ecosystem services are not interdependent, the sub-studies are randomly presented. The ecosystem services addressed in this report include, the art value (Chapter 2), the research value (Chapter 3), the medical and pharmaceutical value (Chapter 4), the climate regulation value (Chapter 5), the pollination value (Chapter 6), the coastal water quality function (Chapter 7), the amenity value (Chapter 8), the cultural value (Chapter 9) and an analysis calculating the ecological footprint of cruise ships in the coastal waters of Bonaire (Chapter 10).

[1] A fair share of the ecosystem services addressed in this study were valued as part of a MSc course Environment Resource Management (ERM) at the Insititue for Environmental Studies (IVM) / VU University www.environmentmaster.nl.

2 Art value

Esther Wolfs, Carina Kalke-Kats, Jorge Amrit Cado van der Lely, and Pieter van Beukering

2.1 Introduction

Artists are inspired by their surroundings. Such is also the case on Bonaire, where the natural scenery of the island stimulates artists to use components of nature in their work. It is important to understand if and how the flora and fauna of the island influences the works of Bonairean artists.

Figure 2.1 Examples of Bonairean art illustrating the fact that nature and culture in Bonaire are strongly connected.

2.2 Methodology

Hence a survey was conducted, see appendix 1 for the questionnaire. From a list of 22 artists 13 were interviewed, from the 6 photographers identified, 2 were interviewed and 2 local libraries and 2 bookstores were questioned. Respondents filled out the questionnaire and put the questionnaire in a sealed envelope in order to achieve complete confidentiality.

Table 2.1 Overview of list of artists, photographers and libraries.

Artists	Jan Art Gallery	Dominique Serafini
	Dirk de Boer	Wil Dijkstra
	Jake and Linda Richter	Germaine Nijdam
	Wolmoet Jansen	Renate van der Bijl
	Rob Mienis	Henk Roozendaal
	Catharina Tegelaar	Airbrush: www.edgerart.com
	Fred vd Broek	Craft Market: Mylene Oudejans
	Luz Aida Franco Wesselius	Judith Spierings
	Jose Smit	Jannie Koning
	Janneke Knoester	Dion
	Ans Klein Heerenbrink	Marco di Gianvito
Photographers	Bon Photo	Bonaire Panoramas
	Fish Eye Photo	Buddy Dive Digital Photo
	Scuba Vision	Several part time photographers
Libraries	Addo's Bookstore	STINAPA library
	Flamingo Bookstore	Openbare Bibliotheek Bonaire

2.3 Results

Although the small sample size does not allow any significant conclusions to be drawn, it provides an idea of how important nature is for artistic work on Bonaire.

Most artists acknowledge that nature plays an important role in their work. Nearly 70% of the individuals that were interviewed agree that the contribution of nature is “important” to “very important” (Figure 2.2).

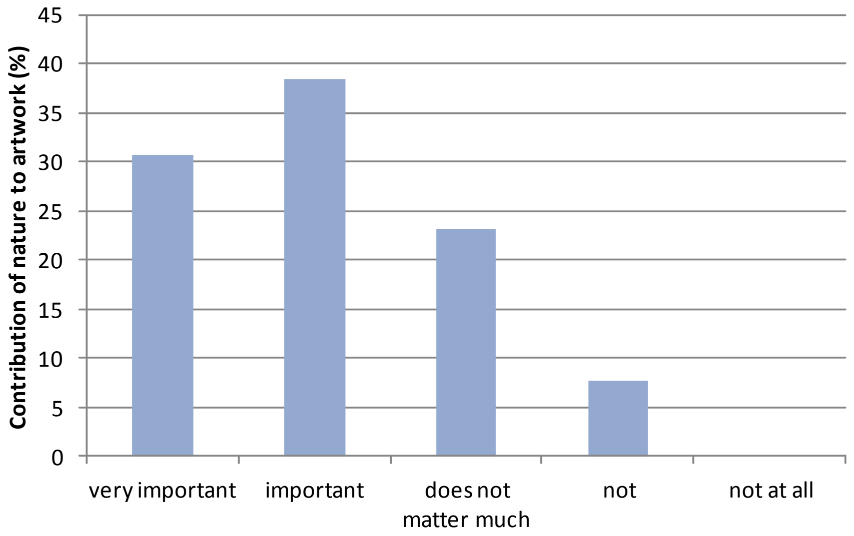


Figure 2.2 Degree to which nature contributes to the work of the artist

A total of 92% of the questioned artists indicate that more than 50% of their work is related to nature or has in some way been inspired by nature. Animals are an important component, since 92% of the interviewees stated that their work was inspired by animals (including donkeys) (Figure 2.3).

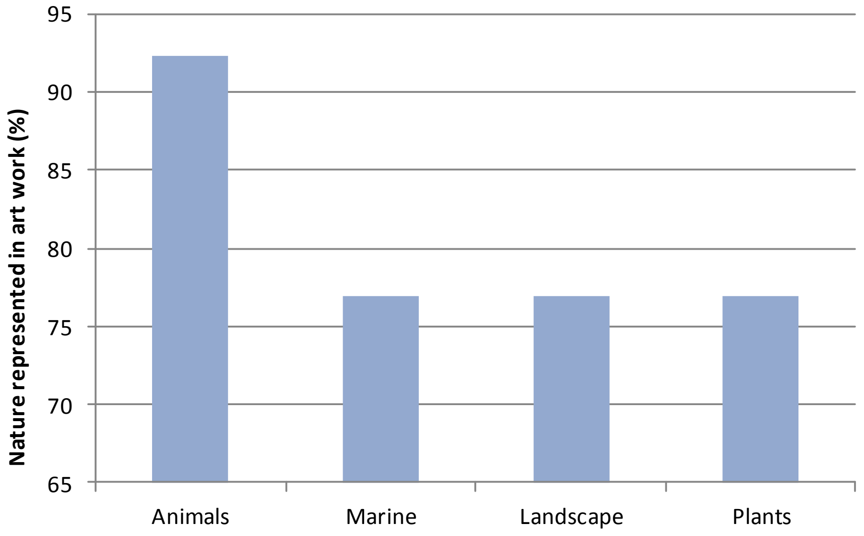


Figure 2.3 Degree to which nature is represented in the work of artists

Figure 2.4 shows how concerned artists are with the degradation of nature and their concern with specific types of ecosystems or elements thereof. Not surprisingly, the artists are mainly concerned with the terrestrial landscape. In comparison, landscape degradation scores one-third higher than marine ecosystem degradation and two-third higher than plants and animals. The high concern for landscapes can be explained because of the importance of scenery in their work. Another observation that can be made from Figure 2.4 is that the marine environment receives the most varied judgement. One half of the artists are not very concerned while the other half is somewhat to very concerned. A possible explanation for this diverse perception is the fact that the marine environment is less directly visible for artists and therefore may create some emotional distance with a part of the artistic community.

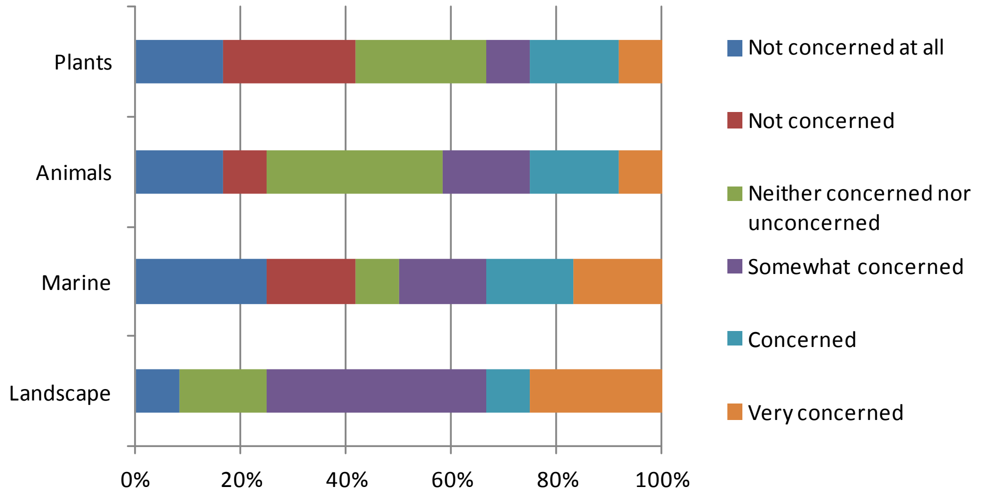


Figure 2.4 Degree to which the interviewed artists are concerned about the degradation of specific characteristics of nature on Bonaire

When asked how degradation of nature would affect their work over 30% answered 'quite a bit'. On a more drastic note, over 30% of the artists stated that 'without nature they cannot produce their work' (Figure 2.5).

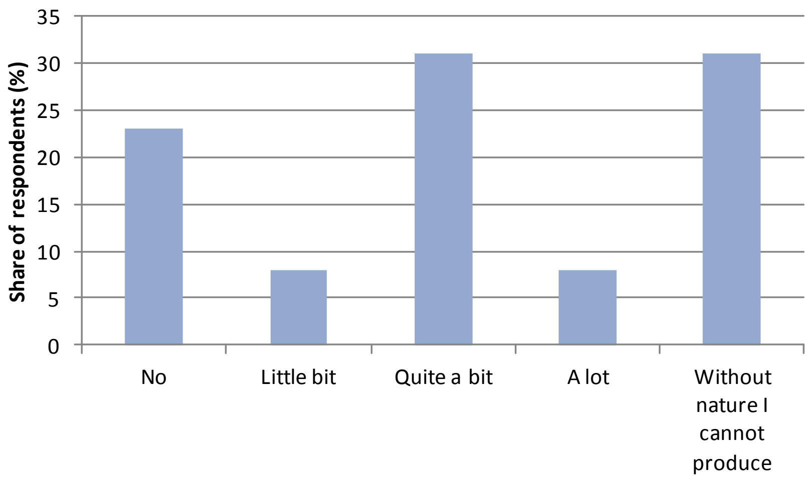


Figure 2.5 Perceived level of impact of degrading nature on the work of the interviewed artists

In order to determine the economic value of nature as an input in the art sector we first need to determine the overall economic value of the art industry on Bonaire. Three art categories are taken into account: (1) paintings and other artwork; (2) photography, and (3) books and postcards.

In total, approximately 7,000 works of art are sold every year on Bonaire. Assuming an average value of $20 per artwork, the total value of artist is determined at $140,000. From the survey we conclude that at least 75% of these works are nature related, resulting in a nature value of paintings of $105,000 per year. About 33% of the artwork is estimated to be sold to residents and 67% to tourists visiting the island.

The photographers are very much aware of the importance of the nature of Bonaire for their work. They all agree to the statement "Without nature my business would fail". Healthy coral, diversity and abundance of marine and terrestrial life are considered very important. From the estimated revenue costs for capital expenditures are deducted and the gross revenue of photographers that can be contributed to nature is estimated at $250,000.

Finally, a total of 24 books, 8 ID cards and numerous postcards that are related to nature have been sold on Bonaire in 2011. Especially books on reefs, or reef guides and books about tropical birds sell on the island. Postcards with a nature related picture sell exceptionally well on Bonaire. For example postcards that have a flamingo or iguana or representation of Klein Bonaire sell very well.

Table 2.2 shows the calculation that results in the estimate of the nature-related value of the art sector on Bonaire. The largest contributors to the art value are photographers that rely entirely on the beauty of nature. Writers and painters generate similar values related to nature on Bonaire. The total nature related art value produced by artists, photographers and writers on Bonaire is estimated to be $460,000 per year.

Table 2.2 Total estimated gross revenue of nature to art

Category	Amount	Unit	Unit price	Gross value	Nature-link	Nature value
Art work	7,000	Art works	$20	$140,000	75%	$105,000
Photography	N.A.	Gross value	N.A.	$250,000	100%	$250,000
Books	7,000	Books/cards	$15	$105,000	100%	$105,000
Total value				**$495,000**		**$460,000**

2.4 Conclusion

The importance of art goes far beyond economic domain of money, revenues and profits. It inspires the world, it records the soul of society and it provides employment to a wide range of creative and productive people. At the same time, the sector provides important stimulus to the economy. This is especially true in Bonaire where both supply and demand for art are abundant. The supply of art is provided by a wide range of well-trained and hard working artists who use their surrounding as a source of inspiration for their products and services. Clearly, nature plays a crucial role in the production process of art on Bonaire. The demand of art consists of the thousands and thousands of tourists visiting the island, who are keen to bring home a piece of art to memorise the beauty of the island upon their return. Moreover, the beautiful photographs and books produced on Bonaire are distributed to clients across the world. Given the explicit demand and supply of art on Bonaire and its strong dependence on nature, the art sector on Bonaire plays an important role in the overall economy and provides an additional reason to manage nature well on the island.

Appendix 2A. Questionnaire artists Bonaire

Survey

This research is investigating the contribution of nature to the art of Bonaire. With nature we mean all flora and fauna including landscapes and the ocean. This research is part of a research project, which is called *What is Bonaire Nature Worth?* Art has an important and special contribution to culture on Bonaire, therefore we wish to better understand the role of nature in Bonairean art from your, the artist's, perspective. We highly appreciate your cooperation.

1) How much does nature contribute to your work on a scale of 0 (not at all) to 5 (very much so)?

0 1 2 3 4 5

2) Is there anything that you consider typical of Bonaire's nature represented in your work and if so, what?

3) What percentage of your artwork has nature of Bonaire as the theme or is inspired by nature of Bonaire?

________%

4) What kind of nature is represented in your art? (check all that apply)

- o Marine
- o Landscape
- o Animals
- o Plants
- o Other ______________________________

5) On average, how many total pieces do you sell each year?

6) What percentage of your sales are of Bonaire nature themed/ inspired pieces?

7) What is the average price for one of your pieces in USD?

8) How much artwork do you sell to tourists and how much to residents of Bonaire per year in percentages?

Residents: % Tourists: %

9) For each below, indicate on a scale of 0-5 how concerned you are about the degrading condition of the following elements of nature on Bonaire? 0 is not concerned at all and 5 is very concerned

- Marine
- Landscape
- Animals
- All of the above
- Other …

10) Would this degradation affect your work negatively as well?

- No
- Little bit
- Quite a bit
- A lot
- Without nature I cannot produce art

11) How important is the nature of Bonaire for you?

Thank you for the taking the time completing this survey. Your responses will be recorded anonymously. When finished, please fold the survey and seal it in the envelope provided.

3 Research value

Esther Wolfs and Pieter van Beukering

3.1 Introduction

Nature in Bonaire provides important services for research and education. The marine and terrestrial environment of Bonaire is subject for a large group of academics who conduct and publish innovative research based on these unique and easily accessible ecosystems. Without the presence of healthy ecosystems, Bonaire would not attract large numbers of researchers nor would Bonaire's nature be a source of inspiration for many educational activities on the island and beyond.

3.2 Methodology

The research value is estimated in a rather straightforward manner. All research expenditures in 2011 for Bonaire are included in this value category. Management and enforcement funds are excluded given the difficulty in obtaining this information as well as these expenditures represent a financial cost of nature rather than a benefit.

Data is collected from governmental and non-governmental groups. To determine this we have used the market directly to obtain information about the value of the direct research expenditures through a brief survey. More specifically, all relevant research organisations were asked 1) how much money they spend on research, 2) how many researchers and 3) their number of interns. The relevant research organisations taken into account are: STINAPA, CIEE Research Station, Echo, Sea Turtle Conservation Bonaire, Wayaká Advies & KibraHacha Foundation, Salba Nos Lora, Dutch Caribbean Nature Alliance, WKICS and local government Department of Spatial Planning.

3.3 Results

The results of the data search and the survey among research organisations are summarised in Table 3.1 (e.g. in terms of labour input) and in Table 3.2 (in terms of economic value). A total of between the 685,000 to 1,500,000 USD in 2011 has been spent directly on research with between 8 to 12 persons residing on Bonaire are involved with research. We have estimated that research value of research executed by parties on Bonaire represent gross revenue of around 570,000 USD and 650,000 USD.

Moreover, between the 20 and 42 researchers visit Bonaire for on average 7 days of research and around 40 students/ interns spend time on Bonaire doing an assignment. Assume that most students spend between 2 to 3 months on Bonaire a total amount of time spend by external students and researchers is between 3,200 days and 3,350 days on Bonaire. Another assumption is that this group spends on average around 100 USD for food, accommodation and transport per day. That would mean total gross revenue of 320,000 USD and 335,000 USD per year.

External parties[2], such as CARMABI, the University of Wageningen and Witeveen + Bos also add research value. They perform research on a regular basis on Bonaire for a total estimated budget of 350,000 USD to 500,000 USD in 2011.

Table 3.1 Overview of parties researched (2011)

Organisation	Number of researchers
STINAPA	24 residents (2 researchers) 8 interns 10 to 30 visitors
CIEE Research Center	4 to 6 residents (3 researchers) 20 students 5 to 7 visitors
Echo	2 residents 1 – 3 interns
Sea Turtle Conservation Bonaire	2 residents 2 to 3 interns
Wayaká Advies & KibraHacha Foundation	5 residents (more project related work)
Salba Nos Lora	1 resident
Dutch Caribbean Nature Alliance	7 – 9 residents (none of them purely research) 2 to 3 visitors for research
WKICS	1 resident 2 visitors 6 interns
Department Spatial Development – Island Territory Bonaire	2 policy advisors

In this research value the value derived from the tickets of the interns and external researchers are not allocated to Bonaire's ecosystem services. In total we have calculated a total gross research value between 1,240,000 USD and 1,485,000 USD in 2011.

Table 3.2 Contribution of different parties to total research value

Parties	USD in 2011
Research organisations on Bonaire	570,000 – 650,000
Researchers and students visiting Bonaire	320,000 – 335,000
External research organisations	350,000 – 500,000
Total	**1,240,000 – 1,485,000**

2 For more information on Carmabi visit www.carmabi.org, and for the Wagingen Univesritry visit www.imares.wur.nl and www.alterra.wur.nl and www.lei.wur.nl and for Witteveen + Bos visit www.witteveenenbos.nl.

4 Medical and pharmaceutical value

Andrea Brock, Miguel Ferrer and Samantha Scholte

4.1 Introduction

Medicinal plants play important roles in many traditional societies. The healing properties of herbal medicines have been recognized in many ancient cultures thousands of years ago. Their collection and usage not only constitutes a source of income, but is also indispensable for health and identity, especially in non-Western societies. Whereas in the “developed” world, 25% of all pharmaceutical products are based on plants and plant derivatives, in non-Western societies, this number exceeds 75% (Principe in Brown, 1994: 739-40).

Balick and Mendelsohn (1994) report similar figures about Belize; accordingly, “traditional medicines are currently the basis for much of the primary health care delivered in tropical nations, […] traditional practitioners provide up to 75% of the primary health care needs of rural people” (1992: 128). Brown further emphasizes that “the cultural role of these plants is central to how they are utilized and how their habitat is managed” (1994: 740).

Besides these local benefits, biodiversity – especially in tropical forests, the deep sea and coral reefs – is important for the development of pharmaceutical treatments and drugs. As Baker and colleagues affirm, “over the last 50 years, the pharmaceutical industry has benefitted greatly from natural product sources, especially in the fields of infectious diseases and oncology” (Baker *et al.*, 2007: 1225).

The purpose of this Chapter is to economically value the benefits of species and ecosystem functions that are relevant for medicinal and pharmaceutical purposes.[3]

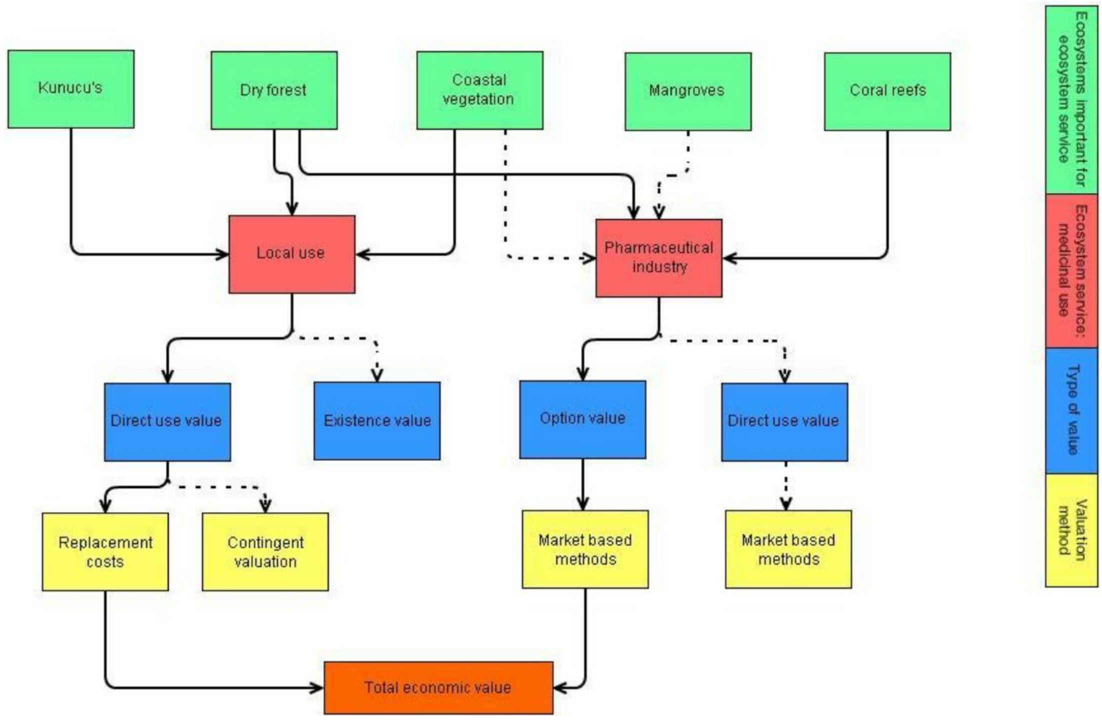
For local medicinal use, all terrestrial ecosystems are important, as people are allowed to extract small amounts of plant species from all ecosystems (Frank Slobbe, personal communication). As for pharmaceutical use, we will only focus on coral reefs and dry forests as these are currently most researched and used by pharmaceutical companies. We will now briefly elaborate on each usage.

Few studies exist which take into account both of these benefits. In the following Sections, we will review the existing literature separately, starting with local benefits. We first give a short overview of the methods used to valuate medicinal plants, before proceeding to the results of these studies.

4.2 Methodology

As mentioned previously, for the economic valuation of the medicinal value of ecosystems on Bonaire a distinction has been drawn between benefits of the ecosystem service to the local population and benefits to the pharmaceutical industry. In the model shown in Figure 4.1, this distinction, as well as the ecosystems contributing to both values, is illustrated graphically.

3 Medicinal plants and herbs not only provide important inputs for pharmaceutical drugs and other sorts of medical treatments, but traditional medicines are also important for health and cultural identity of local communities.



Note: Dotted arrows indicate possible important connections between certain factors, however these will not be of importance in our economic valuation.

Figure 4.1 Analytical framework

4.2.1 Local use

Literature

Despite the importance of medicinal plants for local use, until today, "most analyses undertaken have focused on [...] the value of medicinal plants and on the option value of maintaining biodiversity as a source of pharmaceuticals" (Brown, 1994: 740). Only very few authors have explicitly valued the benefits which ecosystems (usually tropical forests) deliver to local communities. The bias towards tropical rainforests is probably due to the fact that "traditional rainforests are currently the basis for much of the primary health care delivered in tropical nations" (Abelson, 1990).

Balick and Mendelsohn assessed the economic value of traditional medicines from tropical rainforests in Belize through a direct market-price based approach (1992). After having created an inventory of plant material in two particular (representative) plots of land, they collected all "marketable medicinal plants" and multiplied them with local market prices of $2.80 per kg, paid by local pharmacists and healers (1992: 129). The deduction of labour and other costs and the assumption of an either 30 or 50 years rotation resulted in monetary values between $564 and $3,054 per hectare. This range represents the present value (to be achieved through total clearing). Adopting a system ecological approach and taking into account rotation as well as real interest rate would render annual net revenues of $19-61 per ha of forest (Brown, 1994: 743). By looking at the value of these two plots in terms of stocks and fluxes, one can arrive at values of sustainable usage, which are crucial for decision makers in the end.

Balick and Mendelsohn's approach has been criticized on two fronts. First, it does not take into account that "the unprocessed plant may undergo a 10-100 fold increase in price along its path", thus the real value may be significantly higher (Brown, 1994: 744). On the other hand, Pearce and Puroshothaman argue that these values "would be quickly depressed if very large tracks of land were devoted to medicinal plants" (1992: 13).

Alternatively, in order to value non-marketed medicinal plants, researchers have used the opportunity cost approach (Brown, 1994: 744). Alcorn (1989) calculated the costs of avoided doctor visits in Mexico. His valuation is based on the assumption that the average family will attend a doctor about 12 times a year, and the cost for average doctor's visit is estimated at about $4.55. Multiplying these values, he arrives at a total economic value of the medicinal plants of forest groves of $48.60 per hectare per year. However, this value does not take into account the time spent collecting and preparing medicines, as he himself acknowledges. Further, it is based on assumptions of "direct substitutability", which may not correspond to reality (Brown, 1994: 744).

One last remark should be made about the potential to value medicinal plants and genetic resources financially if a market for medicinal resources demanded by companies exists. As Simpson and colleagues state; "markets for transactions in indigenous genetic resources are just beginning to emerge [with] payments of between $50 and $200 per kilogram for samples" (Simpson *et al.*, 1996: 167). However, no valuation studies in this domain exist yet.

Method applied

The recently conducted household survey conducted on Bonaire (Laclé *et al.* 2012) showed that a large part of the population regularly collects and uses local herbs and other medicinal plants for medical treatment. Two-third of the inhabitants who were surveyed make use of local plants as an alternative to modern medicine or prescription drugs. The frequency is illustrated in Figure 4.1.

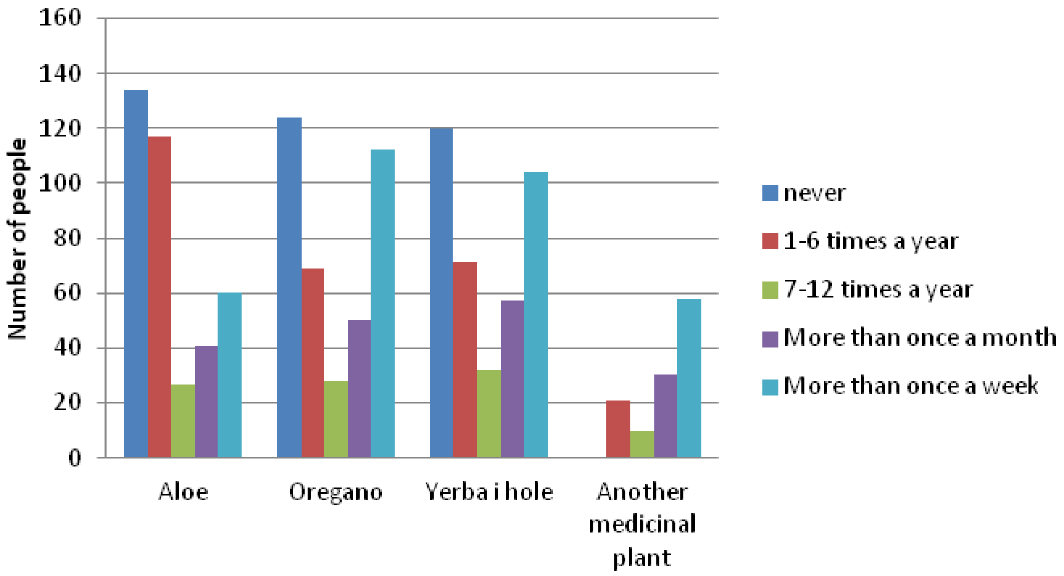


Figure 4.2 Use of medical plants by the residents of Bonaire

Almost 30 plants species with healing characteristics were mentioned by the respondents (See Annex XX). The physical complaints for which plants were used include the following:

- Fever
- Headaches
- Diabetes
- Rheumatic problems
- Stomach aches
- Malaria
- Weight problems
- Skin care
- Tumour treatment

The local use of medicinal can be valued either through direct use values or through existence values (see Figure 4.1). The latter also entails cultural and identity-related values which cannot be valued monetarily. The closest estimation could be contingent valuation based on WTP by the local population (which lies outside of the scope of this report). However, this approach is also only an approximation. Nevertheless, these values should be kept in mind and taken into account by decision makers.

The direct use value of the medicinal plants of Bonaire will not be calculated by means of a market approach, since no mature local medicinal market exists (Esther Wolfs, personal communication), but through opportunity costs. In order to do so, we will first calculate the amount of money saved in doctor's visits, and second, the amount of money saved in buying modern (Western) medicines. Although in the literature reviewed, we found out that Alcorn actually presumed perfect substitutability between the two, we assume that the usage of herbal treatments and traditional medicine will not entirely replace doctor's visits.

Instead, we estimate a 25% reduction for three reasons. First, many inhabitants use medicinal plants only occasionally, rather than regularly (see figure 3). Second, in order to stay credible, it is always advisable to stay at the lower limits of a valuation. Third, inhabitants of Bonaire tend more frequently to visit the doctor in order to receive a doctor's note for sick-leave, rather than to undergo actual medical treatment (Esther Wolf, personal communication). The first two assumptions also apply to the purchase of modern medicines. Thus, in order to calculate the monetary value, we multiply the cost of a doctor's visit ($) with the average number of doctor's visits (frq), the population (pop), the percentage of the population which uses medicinal plants (users) and finally with the assumed reduction of doctor's visits (red).

$$Y = \$ * frq * pop * users * red$$

In order to calculate the amount of money saved from spending on modern medicine, we multiply the (assumed) average of money spent on medicine, adjusted for income ($/med) with the percentage of the population which uses medicinal plants (users) and the assumed reduction of medicine purchase (red).

$$Y = \$/med * pop * users * red$$

4.2.2 Pharmaceutical use

Literature

Ascribing a monetary value to medicinal plants can be based on existing use values or option values (Pearce and Puroshothaman, 1992). Existing use values, i.e. direct use values, are those brought forward by the direct use of an ecosystem, e.g. commercial sales of plant based drugs. Option values relate to future use values, i.e. 'the importance people place on a safe future, either within their own lifetime or for future generations' (de Groot, 1994: 156). It can be compared to an insurance premium paid to guarantee access to a resource of uncertain future supply (Brown, 1994). It is estimated that our planet is inhabited by between 10 and 100 million living species (Simpson *et al.*, 1996: 165). However, less than two million out of these have been "properly described" until today (MEA, 2005) and "far smaller numbers have been subjected to chemical or genetic analysis" (Farnsworth in Simpson, 1996). Tropical forests, for example, are "a rich source of unknown chemicals that may eventually prove useful to medicine" (Balick and Mendelsohn, 1992: 128). Thus, maintaining biodiversity as a source of pharmaceuticals may even make sense economically.

Several ways to quantify direct use values of medicinal plants have been proposed, mostly on the basis of commercial drug sales. Farnsworth and Soejarto calculated the "dollar value that can be placed on a single plant species now growing in the United States, should it become extinct [by the year 2000]" (1985: 231), by looking at the active ingredients of medicinal plants present in drugs consumed by US citizens. Based on the fact that 40 out of 5,000 flowering plant species in the US are relevant to commercial drugs, they calculate a success rate of 1/125 for drug discovery. They then assume that 10% of all species of flowering plants will become extinct – if appropriate conservation measures are not undertaken – to calculate the value of "potentially useful medicinal plants" lost. Farnsworth and Soejarto come to a total value of $3,248 billion for 16 lost plant species ($203 billion per species) in the year 1980 (Farnsworth and Soejarto, 1985).

Instead of looking at the actual market value of plant based drugs, Principe goes one step further by looking at the value of drugs in terms of their "life-saving properties", using a value of a "statistical life" (1989). Accordingly, market values do not capture all benefits society receives by medicinal plants. He therefore calculates the costs of a disease to society, where impact could have been avoided through the use of plant based medicines. Taking cancer as a reference case, he calculates benefits ranging from $34 billion to $300 billion based on the average value of a 'statistical life', which is assumed to be worth between $1.5 and $8 million, and consequently the amount of lives saved by the use of plant-based anti-cancer drugs in the US. If non-cancerous diseases are included, benefits may even rise up to between $200 billion and $1.8 trillion (Ibidem).

The studies previously mentioned have been criticized for not taking into account costs associated with drug development. Some scholars, such as Artuso and Aylward, try to calculate a 'net economic value' of medicinal plants by adjusting for research and development costs as well as biodiversity protection costs and royalties paid (Artuso, 1997; Aylward, 1993). Moreover, Pearce and Puroshothaman acknowledge the importance of taking into account the 'prevailing institutional capability to capture the values of discoveries', leading to exaggerated valuations for the host country (1992: 8). Especially when host countries are developing nations, benefits of efforts to conserve biodiversity undertaken by these countries, are often captured by others. Therefore Pearce and Puroshothaman suggest using 'a factor representing the institutional framework [that] should be applied to the ex-post discovery valuation', depending on the existence of a licensing structure, whether the "research conducted in the host country causes other leakages in the economy", and the ability of the host country to carry out this research domestically (Ibidem). They call this factor rent capture (a). In accordance with Ruitenbeek (1989) they then distinguish expected production value, i.e. the patent value of one discovery, from the 'capturable' production value.

Building upon studies conducted by Farnsworth and Soejarto (1985), Ruitenbeek (1983) and Principe (1989), Pearce and Puroshothaman develop a model to determine the option value of a unit of land as biodiversity support, while acknowledging "considerable data deficiencies" (1992: 9). They take into account the probability of finding a drug (p), the value of this drug (v), royalties paid (r) and rent capture (a). They estimate the value of a drug by looking at the actual market value of the plants when traded (I), by looking at the market value of the drugs of which they are source material (II) and by looking at the value of the drugs in terms of their life-saving properties and using a value of a 'statistical life' (III). Based on the value of a 'statistical life' of $4 million, (III) yields the highest results ($240 billion for the US alone, $720 billion for OECD countries). Prescription-drugs (II) are valued at between $11.7 billion (prescription drugs in the US alone) and $49 billion (worldwide). Lastly, actual market prices of the plants (I) yielded the lowest value, between $5.7 billion (USA) and $24.4 billion (worldwide). Pearce and Puroshothaman then proceed to calculate the value per hectare by multiplying the number of plant species at risk, with the value of drugs, divided by the number of hectares of land likely to support medicinal plants. The results range from $0.1 to $21 per hectare (depending on rent capture).

Simpson and colleagues criticized the aforementioned studies because they calculate an average value, rather than a marginal value of species. They attempt to value marginal species on the basis of their incremental contribution to the probability of making a commercial discovery (1996: 164). The authors calculate the Willingness to Pay (WTP) for 'marginal species' by scientists, which led them to take a rather pessimistic outlook. Accordingly, "only very optimistic researchers [...] demonstrate a substantial willingness to pay" (1996; 179). Consequently, only in 'biodiversity hotspots', such as certain areas in Ecuador, values reach up to $20/hectare. In areas with less genetic diversity values were at one dollar per hectare or less (Ibidem: 180). Simpson then concludes that 'the "private value of the marginal species for use in pharmaceutical research and, by extension the incentive to conserve the marginal hectare of threatened habitat, are negligible" (Ibidem:183).

Most studies on the pharmaceutical value of ecosystems, such as the studies previously mentioned, predict the total value of medicines from tropical rainforests (Erwin *et al.*, 2010). Ruitenbeek and Carter actually focus on the total value of medicines from coral reefs (1999). They attempt to calculate the total economic value of the coral reefs of Montego Bay, Jamaica, by valuing local use, non-use and 'pharmaceutical bioprospecting' values. In their study, potential models used in terrestrial bioprospecting valuations are adapted to value bioprospecting in marine ecosystems. Excluding option values, their model uses "localized cost information for Jamaica, and benefit values and success rates based on proprietary information for marine-based pharmaceutical products in the Caribbean" (Ibidem: 129) and they arrive at a value of $70 million for the Montego Bay reefs. This value corresponds to "equilibrium coral abundance levels" of 43% on available substrate; this equilibrium level has been set by ecosystem model predictions when no additional stress is put on the reef (Ibidem).

Method applied

The coral reefs of Bonaire are considered to be the most relevant ecosystem to the pharmaceutical industry, even though other ecosystems (e.g. dry forests) may be the source of several medicinal plants. However, the genetic diversity found in coral reefs has proven to be especially beneficial for the development of medicines by the pharmaceutical industry. Species living in coral reefs are a rich source of novel chemical compounds, of which the pharmaceutical importance has been revealed through their application to biomedical research (Erwin *et al.*, 2010). These compounds have been found to be relevant in treating a number of diseases, such as cancer, heart disease and human bacterial infections (NOAA, 2011).

In the 70ies, a certain cyclic polypeptide was found in cyanobacteria (blue green algae) living in the coral reefs of Bonaire. The cyanobacteria were extracted and researched for further medical development, during which it became clear that it could be used in cancer treatments. Quite rapidly, researchers were able to develop a synthetic equivalent after which harvesting on Bonaire was no longer necessary. Therefore, the pharmaceutical industry does not play a large role on the island as of today (Esther Wolfs, personal communication). However, coral reefs are still considered an important source of chemical compounds, which may be valuable to drug development.

As can be seen in our model (Figure 4.1), the pharmaceutical use can be divided into option value (the potential use in the future) and direct use value (extracting medicinal plants or chemical structures from the ecosystem directly). The direct use value could be valued through market-based approaches, as was shown in the literature. However since currently no activities of the pharmaceutical industry are undertaken on the island, no commercial drug sales can be traced back to any of Bonaire' s ecosystems. Therefore we will focus on option values rather than direct use values.

Option values were calculated by Simpson *et al.* (1996) based on willingness to pay (WTP) of scientists/ pharmaceutical companies (contingent valuation). Alternatively, Pearce and Puroshothaman calculated option values through a simple model. Since we do not have the resources to perform a contingent valuation study on Bonaire, we will partially use the model described by Pearce and Puroshothaman. In accordance to their method, our function will take in to account the probability (p) of finding a successful drug, number of species (n) and the market value (v) of such a drug upon discovery. Even though we acknowledge the difference between „capturable" production value and expected production value through, rent capture we will not include it into our function since we cannot estimate rent capture. We then come to the following formula:

$$Y = p * v * n \quad \textit{(per hectare)}$$

As mentioned before, the ecosystems we will focus on with respect to pharmaceutical use will be dry forest and coral reefs. This is mainly because bioprospecting largely occurs in coral reefs and forests. Even though most studies focus on rainforests and not so much on dry forests, the model can be applied to dry forests with some adjustments concerning species richness.

4.3 Results

Local Use

To produce a local use value, we calculate the cost ($) of visiting a Doctor as an average on Bonaire, based on the formula we created above (*Y = $ * frq * pop * users * red).* Although citizens of Bonaire do not have to pay for a doctor's consult since the constitutional change of 2010 (Esther Wolf, personal communication), the value is nevertheless still existent, just paid by the government. We estimate the costs of a visit at $20, which corresponds to the price before the constitutional change (Ibidem). Furthermore, we calculate an average frequency of 12 doctor visits per family, following Alcorn (1989). Assuming that every family consists of 2.95 family members (Laclé, 2011), the average number of visits per person would amount to 2.4.

*Y = $20 * 2.95 * 15,000 * 0.67 * 0.25*

Y = $148,237.50

To calculate the "savings" on medicinal drugs (*Y = $/med * pop * users * red)*, we adjust the average spending on medicine per person of the Netherlands (€300, or approximately $414, Gezondheitsnet, 2007) according to the lower GDP of Bonaire[4]. We arrive at average spending of $100. Assuming a reduction of usage of modern medicines yields the following results:

*Y = $100 * 15,000 * 0.67* 0.25*

Y = $251,250

Added up, the total local value of medicinal plants amounts to $ 353,083 per year.

Pharmaceutical use

As explained in the methodology section, the following function was used to come to a value of pharmaceutical use of coral reefs and dry forests: *Y = p * v * n* (per hectare). We will add the amount of hectares (h) of the ecosystem to come to the *economic value*. The probability of success (p), which is applied to both dry forests and coral reef, has been estimated at 1 in 10,000 to 1 in 1000 by Pierce (1989). Pierce based his estimates on discussions with drug companies. Since this is a range, in accordance with Pearce and Puroshothaman (2009), we will take the mean probability: 0.0005 as (p) over a period of 100 years.

Coral reefs

For coral reefs, the potential drug value (v) is based on the study performed by Ruitenbeek and Cartier (1999), where research was done on a similar coral reef. They found hit rates and end use values of $7,775/species. The amount of species (n) per hectare was also derived from this study. Using a standard species-area relationship, they came to an average of 18,000 species per 42 hectares. Per hectare this would translate into 483 species. The total area of coral reefs is 4,372 ha.

*Y = 0.0005 * $7,775 * 483 * 4,372*

Y = $8.2 million ($1,878 per ha) over 100 years

Y = $ 335,750 per year, assuming a discount rate of 4%

[4] The per capita GDP of the Netherlands lies at $40,300 in 2011 (Indexmundi, 2011), whereas the per capita GDP lies at $ 19,000 (DEZA, 2008). Therefore, spending need to be adjusted by a ratio of 2.3.

Dry forests

For dry forests, different numbers need to be used. As it has become apparent in the literature review, most studies focus on tropical rainforests rather than dry forests. Moreover, no information on actual hit rates is available, unlike coral reefs. We therefore adjust the market values found by Pearce and Puroshathaman (1992) acknowledging that better data is necessary to come to more reliable results.

On the basis of plant-based prescribed drug sales, Pearce and Puroshathaman arrive at a market value (v) of $290 million per species from tropical rainforests. As for (n), the amount of species was derived from Figure 4.2 produced in a study on dry lands by the WRI (2004). The figure shows the amount of flowering species in selected countries across the aridity gradient. Assuming that flowering species are of most relevance to the pharmaceutical industry, this figure can be used as estimation. Since Bonaire has an annual rainfall of 500 mm it can be compared to the semi-arid climate of Spain (600 mm per year). The amount of flowering species in dry forest on Bonaire is 10 per 1000 square kilometres, or 10 species per 100 hectares. (n) is thus 0.01 per hectare. The area of dry forest on Bonaire measures 3,360 hectares.

*Y = 0.0005 * 290 million * 0.1 * 3,360*

Y = $ 48.7 million ($ 14,500 per hectare) over a hundred year period

Y = $1,987,500 per year, assuming a discount rate of 4%

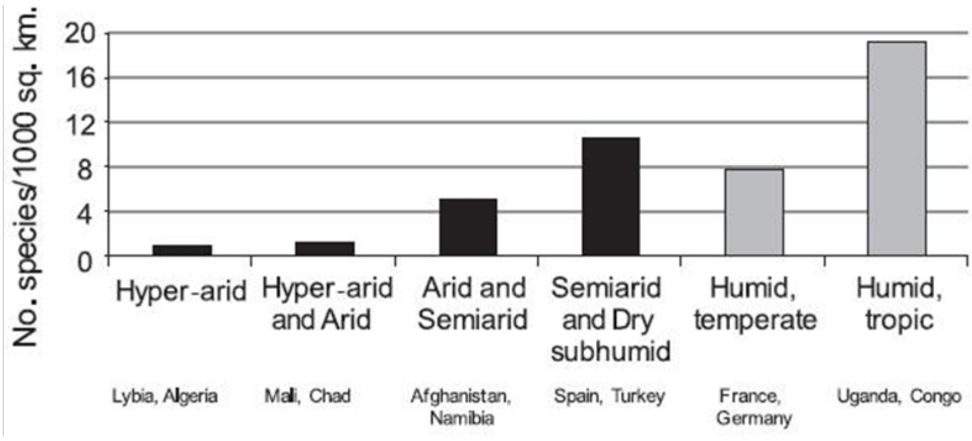


Figure 4.3 Number of species of flowering plants across the aridity gradient (adjusted from MEA, 2005: 634).

Total Economic Medicinal Value

In order to arrive at annual medicinal and pharmaceutical value of nature on Bonaire, the above numbers need to be added up. Yet in doing so, one aspect, which has not yet been considered, should be accounted for: the relative importance of the ecosystems for the pharmaceutical industry from a global perspective. For coral reefs it can be claimed that the reefs are highly diverse and also easily accessible. Combined with the fact that earlier findings have been recorded from coral reefs in Bonaire, the potential value of this ecosystem should certainly be accounted for. This is different for the dry-forest, which is rather small and on a global scale is not very unique. Pharmaceutical firms are more likely to select more vast areas to extract substances and therefore the calculated potential pharmaceutical value of the dry forest of Bonaire is virtually zero. Therefore, in the final calculation, we exclude this value from the overall medicinal and pharmaceutical value of nature of Bonaire. Adding up the other categories, total annual medicinal and pharmaceutical value results in a value of $688,788.

4.4 Conclusions and discussion

The estimates of valuation studies of medicinal plants in ecosystems vary widely. This variation is mainly caused by data deficiencies and different assumptions in the valuation models. For example, Farnsworth and Soejarto (1985) calculate a gross value of medicinal plants in the United States, without taking into account costs associated with drug research and development. Pearce and Puroshathaman develop a model that also takes into account institutional discrepancies, claiming that values are often exaggerated for host countries who are not able to capture the benefits from biodiversity protection. This demonstrates the complexity of choosing the correct parameters in coming to a reliable economic value of ecosystem services.

In order to arrive at better estimates of the economic and cultural values of medicinal plants for local use, a local survey seems most appropriate. Although the substitution approach we have chosen can give good indications of the purely monetary value attached to the plants, it cannot shed light on the effects of the loss of this ecosystem service. Not only would "substitut[ing] Western medicine for traditional healers [...] require a substantial increase in health expenditures" (Balick and Mendelsohn, 1992: 130), but, as Brown pointed out, "traditional systems may be more culturally acceptable and able to meet psychological meets, in a way western medicine may not" (1994: 744). Furthermore, "[m]edicinal plants are symbolically significant in many cultures, often being seen as sources of power. (Hamilton, 2004: 1478). Hence, they may not be easily replaceable with modern Western medicines, as the four advantages of traditional medicines – availability, accessibility, acceptability, and adaptability (Brown, 1995) – may not be given.

With regard to the pharmaceutical use of Bonaire's ecosystems and their biodiversity, the picture is different. Since option values are inherently difficult to calculate, and many undetermined factors (i.e. technological and pharmaceutical innovations, population growth) play a role in these values, the best option is clearly to invest in conservation based on the precautionary principle. As we saw, Simpson (1996) even argues that option values for ecosystems – with respect to bioprospecting – can be neglected; due to the fact multiple species may contain the same compound. Moreover it would take 'a very rosy view to suppose that the probabilities of discovery happen to be precisely those that generate the maximum possible value for the marginal species' (Simpson, 1996: 183).

After having created our own methodological model to calculate the value of medicinal plants on Bonaire, we arrived at a total economic value of approximately $0.7 million per year. The numbers put forward in our model should not be taken for face value, as they lack reliability due to data deficiencies and do not take into account factors such as development costs and rent capture. Still, this study can be seen as a good first effort as well as the basis for further research which creates awareness among society towards the conservation of ecosystems.

In order to translate this evaluation study into policy making, other issues need to be considered. Currently, not all of these values can be realized, for example due to unclear or non-existent property rights (e.g. coral reefs and the case of the pharmaceutical company Pharmamar which discovered cyanobacteria). As Simpson and colleagues indicated: “property rights [on genetic resources] have typically not been well established” and contracts between governments and pharmaceutical companies are “often secret” (Simpson *et al*., 1996: 166-167). These issues may in turn pose obstacles to effective conservation policies based on traditional usage of medicines, as they “depend on the allocation of property rights and the cultural status of herbal medicine” (Brown, 1994: 740).

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Annex 4A. Overview medicinal plants and their effects

Common Name	Scientific Name	USES
Noni	*Morinda citrifolia*	Is reported to have a broad range of therapeutic effects against headache, fever, arthritis, gingivitis, respiratory disorders, infections, tuberculosis, and diabetes. Other uses are anti-inflammation, acne reduction and moisture retention. Noni oil reduced total cholesterol and triglycerides levels.
Pomegranate peel	*Punica granatum*	Is used as a traditional remedy against diarrhea, dysentery and intestinal parasites. The seeds and juice are considered a tonic for the heart and throat, and classified as a bitter-astringent (pitta or fire) component under the Ayurvedic system, and considered a healthful counterbalance to a diet high in sweet-fatty (kapha or earth) components.
Sangura	*Hyptis suaveolens*	Is commonly used as a refreshing healthy drink. Has also traditionally been used and continues to be used as a treatment for diarrhea and antiflammatory.
Sorsaka	*Annona muricata*	The Annona muricata tree produces a delicious fruit, also known as graviola, which is widely consumed by indigenous peoples. The fruit and the leaves are used in traditional medicine for their tranquillizing and sedative properties.
Wilisali	*Croton flavens*	Croton flavens leaf essential oil was found to be very active against tumour cell lines
Yerba Buena	*Mentha longifolia*	It is mainly used for respiratory ailments but many other uses have also been recorded. It is mostly the leaves that are used, usually to make a tea that is drunk for coughs, colds, stomach cramps, asthma, flatulence, indigestion and headaches.
Yerba raton	*Gliricidia sepium*	The tree is used in many tropical and sub-tropical countries for various purposes such as live fencing, fodder, coffee shade, firewood, green manure and rat poison. The sepium is also used for its medicinal and insect repellent properties.
Yerba salu	*Corchorus hirsutus*	The plant has an antioxidant activity, mainly as fibre is used as dietary supplementation with polyphenolic compounds is associated with reduced diet-induced obesity and metabolic disorders in humans.
Yerba seru	*Croton ovalifolius*	Popular uses include treatment of cancer, constipation, diabetes, digestive problems, dysentery, external wounds, fever, hypercholes-terolemia, hypertension, inflammation, intestinal worms, malaria, pain, ulcers and weight-loss.

Basora pretu	*Cordia curassavica*	Leafs are steamed to treat colds and cough; an infusion of the leafs is used to treat infections, rheumatism and arthritis. Due to the anti-inflammatory effect it is also used against skin diseases, malaria, flu and fever.
Flaira	*Jatropha gossypiifolia*	A leaf extract showed significant activity as an anticoagulant for haematological analyses and significant inhibitory activity in different human cancer cell lines.
Hilo di diabel	*Cuscuta americana*	The kidneys play a central role in regulating water, iron composition and excretion of metabolic waste products in the urine. Has been used for treatment of liver and kidney disorders.
Karpata	*Ricinus communis*	An industrially important non-edible oilseed crop, native to tropical and subtropical regions of the world. Can be applied against rheumatic swellings and harmless purgative. Castor oil massaged over the breast after child-birth increases the flow of milk and stimulates the mammary glands.
Korona la virgen / Lamoenchi	*Balanites aegyptiaca*	Many medicinal uses of this plant exist. The fruit is mixed into porridge and eaten by nursing mothers, and the oil is consumed for headache and to improve lactation.
Lemongrass	*Cymbopogon*	It has several uses as an antiseptics, antimicrobial, antioxidant, and anti-Inflammatory. It is consumed as well as drunk in tea to treat anxiety and against coughs, colds, and nasal congestion.
Mampurito / Bolivian coriander	*Porophyllum ruderale*	Has been used for the relief of anxiety, insomnia and as a diuretic. Leaves were found to have antibacterial activity against Salmonella choleraesuis. Has been documented as a traditional treatment for diabetes.
Neem	*Azadirachta indica*	The anticancer properties of the plant have been studied largely in terms of its preventive, protective, tumour-suppressive, immunomodulatory and apoptotic effects against various types of cancer and their molecular mechanisms. Neem products are believed to be anthelmintic, antifungal, antidiabetic, antibacterial, antiviral, contraceptive and sedative.

Sources: Based on Shin *et al.*, 2011, Codd 1983, Grassi *et al.*, 2006, Alison and Flatta, 1999, Hernandez *et al.*, 2006, Oduola *et al.*, 2005, Paul *et al.*, 2011, Pazos *et al.*, 2011, Sylvestre *et al.*, 2006 and Tsai *et al.*, 2011.

5 Carbon sequestration

Pablo Moleman & Natasha Risseeuw

5.1 Introduction

Ecosystems, when healthy and well managed, can often provide a myriad of goods and services beneficial to society. These benefits are referred to as 'ecosystem services'. Climate regulation, the ecosystem service central to this report, deals mainly with greenhouse gas emissions and how to mitigate such effects. The spatial focus of this study is Bonaire which has six ecosystems that provide carbon sequestering properties. These ecosystems are identified as salinas, dry forest, coral reefs, sea grass, mangroves and open ocean. Nonetheless, it is not only useful to know the types of services being provided by a specific ecosystem and their ecological importance, but it is also convenient to know the potential monetary value they posses.

The objectives of this report are:

1. To identify the ecosystems that are relevant to climate regulation in Bonaire with their functions and threats;
2. To describe the different economic valuation methods suitable for climate regulation calculations;
3. To value the overall climate regulation potential of Bonaire.

The structure of this Chapter is as follows. Section 2 defines climate regulation and carbon fixation and sequestration of ecosystems. Section 3 describes the different valuation methods used for this report while presenting the functions and threats of each ecosystem. We will end the study with a results and discussions, mentioning our findings and possible limitations of this desk study.

5.2 Background

Carbon sequestration

Regulating services, the category in which carbon sequestration falls under, are defined as 'the benefits obtained from the regulation of ecosystem processes' (UNEP 2010:1). The benefits derived from regulating services are categorized as indirect use values as they, 'provide benefits outside the ecosystem itself (van Beukering *et al.*, 2007:49). Additionally, identifying the beneficiaries to these regulating processes and estimating how much of the service is provided by the particular ecosystem brings complication in the overall valuation.

Climate regulation, unlike other ecosystem services, is relevant at both global and local scales. Through the emission and/or absorption of greenhouse gases and aerosols, climate regulation is able to have an effect measureable at a global scale (UNEP 2010). At a local scale, on the other hand, climate regulation refers to the ability the physical environment has on managing temperature, rainfall and other climate related issues (Costanza, 1997).

The amount of greenhouse gases absorbed through carbon sequestration and/or fixation in the six different ecosystems distinct to Bonaire is the way in which climate regulation provides its 'service' at a global scale (UNEP 2010). For the purpose of this report, climate regulation will have a global focus and its performance indicators will be measured through the amount of carbon sequestered and/or fixed.

Carbon fixation is the process in which primary producers convert inorganic carbon, such as carbon dioxide (CO_2), to organic components, which contribute to plant development and metabolism (Moura-Costa 1996). The carbon is stored in the wood and in other tissues of the plant until it dies. Thereafter, the carbon is either released back into the atmosphere as CO_2, carbon monoxide or methane (Moura-Costa 1996).

Carbon sequestration 'is used to describe both natural and deliberate processes by which CO_2 is either removed from the atmosphere or diverted from emission sources and stored in the ocean, terrestrial environments, and geologic formations' (Sundquist 2008:1). The definition of carbon sequestration also assumes that the uptake of carbon is not spatially dependent, meaning that local initiatives for carbon sequestration will contribute to global carbon reductions. For the purpose of this report, the focus will be on the natural uptake of CO_2 in the six ecosystems relevant to Bonaire.

Scenarios

In valuing Bonaire's total carbon sequestration potential, we assume two scenarios: conservation and conversion/degradation. Conservation here means the protection of all salinas, mangroves, dry forests, coral reefs and sea grass on Bonaire; conversion being their total conversion[5]. We believe that neither of these scenarios is realistic. However, they serve well to determine the hypothetical maximum carbon sequestration value that could be obtained, for instance (but not solely) through carbon markets.

In most cases, efforts to calculate the total economic value of an ecosystem, as opposed to the value of specified changes, is complicated by the change of marginal benefit over time. But as Bateman *et al.* (2010) note, carbon storage is an exception to this rule. As there is no possible way that Bonaire alone can sequester enough carbon to significantly reduce the problem of climate change, the marginal value of carbon sequestration on Bonaire can be assumed virtually constant.

We further assume that after conversion, be it in the short or long term, eventually all the carbon sequestered will be released into the atmosphere.

We thus base valuation on the combined amount of carbon that will be prevented from entering the atmosphere in the conservation scenario compared to the conversion scenario. This includes carbon sequestered in biomass, as well as extra carbon that might be emitted from the soil after the clearing of mangroves.

5.3 Ecosystems in Bonaire

Now that we have described the scenarios, we will address the relevant ecosystems, their contribution to climate regulation and their respective threats.

Coral Reefs

Function: Coral reefs, as primary producers, act as a sink for carbon, but mainly through the formation of calcium carbonate ($CaCO_3$) (Kinsey and Hopley 1991). Measurements indicate that coral reefs' net production is -0.01 to 0.29 grams of carbon per square meter per day (Kaiser *et al.* 2005). Nonetheless, the negative value

[5] Into e.g. beach resorts etc. according to respective threats (see literature section)

represents that coral reefs also emit some CO_2 back into the water and into the atmosphere (Smith and Gattuso 2009), making coral reefs also a source of CO_2.

Threats: Coral reefs are threatened through various global and local forces. At a global level, there is the issue of climate change, where an increase in ocean temperatures will lead to the destruction and bleaching of coral reefs (WMO 2010). Ocean acidification, another global issue, occurs when coral reefs lose their ability to grow and form their skeletons because of decreased ocean pH caused by CO_2 intake by the oceans (*ibid.)*. These problems, however, lie outside Bonaire's mitigation capabilities and are mostly seen as a global trend. The local threats posed to coral reefs, on the other hand, lie within the control of Bonaire and can be avoided. Within the Bonaire context, the biggest threat posed to coral reefs is through the increase in tourism (Burke and Maidens 2004). The growth of dive tourism, to be specific, has put a pressure on the physical environment, through continued and increased contact of scuba divers, snorkelers and swimmers with corals. Additionally, coastal development projects caused by this increase in tourism further aggravate the problem. Increased nitrogen and phosphorus deposition by hotels in coastal waters further endanger coral reefs. Consequently, the destruction of mangroves does not help alleviate this problem, as they absorb many of the nutrients that should not reach the corals in the first place. Another big threat in the Bonaire and Curacao area is marine-based pollution, which accounts for 45 per cent of the posed damage (*ibid.*). Overfishing is also a threat that, if not dealt with, can escalate into a larger issue.

Sea grass

Function: Sea grass provide a myriad of functions relevant to the marine environment ranging from nutrient cycling to seed production. However, for the purpose of this report, the scope is limited to primary production and carbon sequestration. As primary producers, sea grass absorbs carbon and serve as a food source for many marine organisms such as turtles and manatees. The role of sea grass, in the carbon sequestration process, is by absorbing CO_2 from the water (Laffoley & Grimsditch, 2009). Carbon is then attached to the sediments, which are later either buried or 'transported into the deeper oceans and thus play an important role in long-term carbon sequestration' (Spalding *et al*. 2003:15). The estimated carbon sequestration potential of sea grass is 83 grams of carbon per square meter per year.

Threats: Although there is a global trend towards sea grass degradation, there are also local circumstances that exacerbate the problem. On a global level, sea grass suffer from the combined impacts of various factors such as turbidity, nutrient loading and 'direct mechanical damage' (Spalding *et al*. 2003). Adding climate change to the equation, however, could aggravate the risk to sea grass even further. Although the exact effect of climate change on sea grass is unknown (*ibid.*), there still is an increased potential risk coming from sea-level rises, tide changes, salinization, ultraviolet radiation, among others (*ibid.*). As previously mentioned, coastal development is a threat to Bonaire's coral reefs and therefore, also a threat to sea grass. Tourists' direct contact with this ecosystem is the biggest threat on Bonaire. Swimmers, divers, and surfers are constantly exposed to sea grass when entering and leaving the ocean. Continued contact can decrease sea grass' resilience (De Meyer and MacRae 2006). Furthermore exiting hotels, piers, harbours and other infrastructure all contribute a threat to sea grass as they add pressure to the marine environment. Increased nutrient deposition from hotel waste ultimately affects the amount of light reaching the sea grass, hampering growth and development.

Salinas

Function: Salinas, more commonly known as salt marshes, are intertidal ecosystems that shelter a variety of organisms. Macroalgae, diatoms, cyanobacteria and vascular plants are all found in Salinas and contribute to the removal of CO_2 from the atmosphere (Laffoley & Grimsditch, 2009). Another incentive for protecting Salinas is their limited contribution to the emission of other greenhouse gasses such as methane. This is due to the limited activity of microbes, which are responsible for the production of methane, by the sulphates present in the salt marshes (Chmura 2009). Salinas sequester 210 grams of carbon per square meter per year.

Threats: The threats posed to Salinas are similar to that of coral reefs and sea grass. An increase in construction projects for tourist developments has led to a growing pressure on land availability. As Salinas are located adjacent to the coast, they have a high amenity value (*ibid.*).

Mangroves

Function: Mangrove forests are among the most important carbon sinks in the world, sequestering more carbon than dry forests. Measurements suggest mangrove forests can sequester around 139 grams of carbon per square meter per year (Laffoley & Grimsditch, 2009).

Threats: Around the world, mangroves are disappearing at an alarming rate. About 60% of the total mangrove area is estimated to have disappeared (De Meyer & MacRae, 2006). The main threat to mangroves is land conversion for coastal development (Ong, 2002). Another factor that needs to be taken into account is the soil. Mangrove soils contain large amounts of both carbon (Ong, 1993) and methane (Strangmann *et al.*, 2007), the latter being a greenhouse gas about 72 times stronger than CO_2. When the mangroves are cleared, the exposed soil turns into a carbon source. Ong (2002) estimates that digging up 2 meters of soil results in the return of 70 tonnes of carbon per hectare per year.

Dry Forest

Function: This terrestrial ecosystem, the dry forest, is mostly found in semi-arid conditions where the average temperature is above 17 degrees Celsius and the average rainfall falls between 250 – 2000 mm (Murphy and Lugo 1986). The role of dry forests in climate regulation is through carbon sequestration. Murphy and Lugo (1986) estimate a total net primary production of dry forests to be 8 – 21 tons per hectare per year. Nonetheless, to be able to exactly find Bonaire’s dry forest’s sequestering potential would require more specific information on the area such as soil quality, tree age and composition which are factors we could not account in this report.

Threats: The major threat for dry forests in Bonaire is the overgrazing of free ranging goats and donkeys. The forest cover in Bonaire is partly protected through national parks such as the Stinapa National Park. Although free roaming goats are also present in the park. And the high demand for land sourcing from the growing tourist economy could lead to increased pressures in land cover.

Open ocean

Function: The open ocean is an important carbon sink, taking up more than a quarter of anthropogenic CO_2 (Khatiwala *et al.*, 2009). Sabine *et al.* (2004) estimated that between 1800 and 1994, around 118 Petagram of human-released carbon was sequestered by the ocean. Oceanic carbon sequestration is driven by two processes:

the solubility pump and the biological pump (Raven & Falkowski, 1999). The solubility pump is CO_2 being dissolved in the sea water and being transported by thermohaline circulation. The biological pump is mainly caused by primary production of phytoplankton.

Threats: The open ocean is threatened by many factors, including overfishing and pollution. Though each of these factors poses a serious threat to the stability of oceanic ecosystems, we could not conceive of mechanisms in which they influence carbon sequestration potential. It might well be that the global oceanic carbon sink is unaffected by them. There have been studies that suggested a possible reduction in oceanic carbon sequestration potential due to global warming (Sarmiento *et al.*, 1998; Cox *et al.*, 2000). These mechanisms might cause a positive feedback loop accelerating climate change. At the same time, the climate regulation value of the open ocean would be reduced. But since the people of Bonaire have no probable means of protecting their open ocean against global warming, it is impossible to determine a value. Therefore, we chose to exclude open oceans from the economic valuation procedure.

5.4 Methodology

Figure 5.1 shows the different steps that lead to the economic valuation of the climate regulation function of the main ecosystems of Bonaire. For monetizing the value of carbon two different methods can be applied: price-based and cost-based approaches.

Market price-based approach

Since the establishment of the Kyoto Protocol in 1997, carbon has a market price. Although carbon markets are not yet fully functional, there is already considerable carbon trading between nations. There are different types of tradable carbon (carbon credits), with different prices that are linked to varying degrees. The market price of a tonne of carbon is around US$12.

Two types of carbon credits that are important in respect to carbon sequestration are AAUs and RMUs. AAU stands for Assigned Amount Units and are credits that can be sold between governments. RMUs are credits that countries can obtain for preserving their emission sinks (if threatened) and that can be converted into AAUs. In the case of Bonaire, it could be feasible to obtain RMUs, convert them to AAU's and then sell them on the carbon market.

Like any market price, carbon prices are determined by supply and demand and fluctuate. Besides their relative scarcity, pricing can also depend on several contractual issues or the risk in delivering them to the final costumer. As they only reflect market value, these prices are often criticized for not considering the actual costs of climate change to humanity.

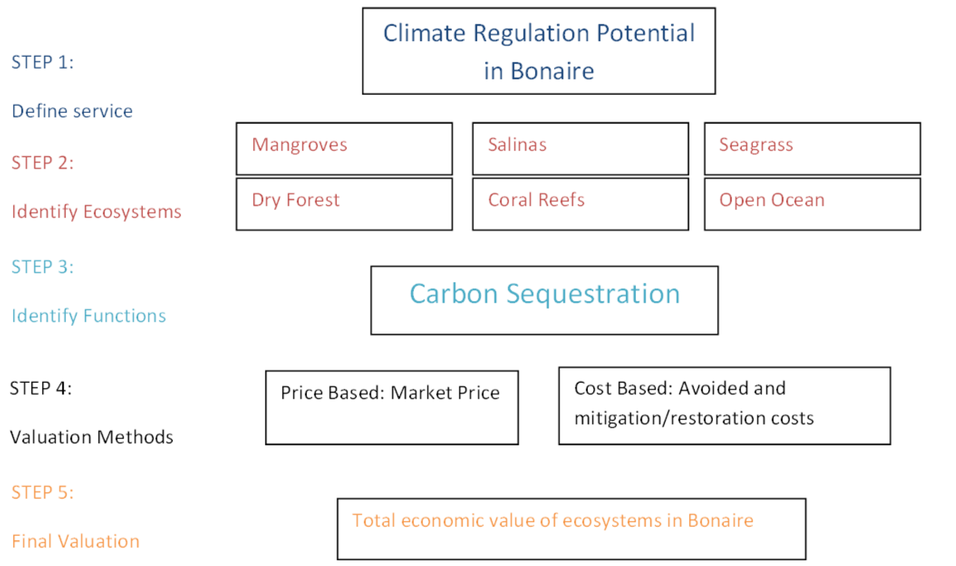

Figure 5.1 Methodological framework for carbon sequestration

Societal cost-based approach

If the market price of CO_2 is indeed disconnected from the actual value or significance of carbon sequestration to people's lives, a cost-based approach might be more appropriate. For this, we need to determine either avoided costs or mitigation/restoration costs. Avoided costs could for instance be the costs of adaptation to global warming, e.g. building higher dikes. Mitigation costs are costs made to reduce the amount of carbon in the atmosphere in other ways than natural carbon sequestration; for instance underground carbon storage, the development of clean energy solutions or the costs of reducing consumption. Restoration costs are the costs of repairing damage when mitigation and adaptation have failed; of course, when it comes to people's or animals' lives, these costs are hard to monetize. Whichever of these cost-based approaches we use, it seems probable that the value of a tonne of CO_2 is significantly higher than market price. We believe this price however to be more 'real' in terms of its actual relevance.

The major downside of cost-based approaches is that it is almost impossible to predict the future costs of global warming, taking into account all uncertainties and different scenarios. Van Drunen *et al.* (2010) also note that the damage of global warming is spatially diverse – some areas might actually profit from climate change – and that damage could increase with time as temperatures go up. Stressing the difficulties in estimating the damage of global warming, is not to say that it hasn´t been attempted. Hundreds of studies have done it, the Stern Review (Stern, 2006) being perhaps the most cited. This report, issued by the British Government, puts the total costs of climate change at 5% of global GDP per year and calls it "the greatest and widest-ranging market failure ever seen".

Tol (2008) has done a meta-analysis of more than 200 studies estimating the costs of climate change. In his analysis, the Stern Review is actually an outlier on the high side. To avoid going into a more detailed discussion on climate modelling, we have decided to use the mean distilled by Tol (2008) from the literature as a conservative estimate. Tol's mean value is 127 US$ /tC (Tol, 2008: Table 1, Fisher-Tippett), with a 1% chance of costs being higher than 1655 US$/tC. Van Drunen *et al.* (2010) corrected this number for inflation, putting the value of a tonne of CO2 at US$ 169.

5.5 Results

The general information on the carbon sequestration potential of our different ecosystems can now be combined with Bonaire-specific information in order to perform a benefit transfer. Table 5.1 lists the ecosystems and the respective surface areas they take up in Bonaire. Note that the open ocean has been excluded from this overview. Dry forest is by far the most productive ecosystem in terms of carbon sequestration per unit area. Combined with a relatively large area, dry forest contributes more than 80% to the carbon sequestration by ecosystems of Bonaire.

Besides carbon sequestration of the standing stock, we also need to account for the potential carbon emissions that occur when an ecosystem is destroyed. This avoided emission from the soil is only relevant for mangrove ecosystems that emit 70 tonnes of carbon per hectare per year. When adding this amount of 8,330 tonnes of carbon per year, the total carbon amount captured by all ecosystems of Bonaire amount to 111,318 tonnes of carbon per year.

We can now determine market price and cost price by multiplying the price of a ton of carbon. We adopt the market price ton of carbon at times of the research (i.e. $12 per tonne) and multiply this by the total amount of carbon captures by the ecosystems of Bonaire (i.e. 24,154 tonnes). This results in a carbon value of US$ 1,340,000 per year.

Table 5.1 Basic information on ecosystems

Ecosystems	Carbon sequestration per unit/time	Surface area in Bonaire	Gross carbon sequestration
Salinas	2.1 t/ha/y	864 ha (Frietas *et al.*, 2005)	1,814 t/y
Dry Forest	8 - 21 t/ha/y	7,995 ha (WSNP)	115,927 t/y
Coral Reef	-0.04 – 1.06 t/ha/y	2,700 ha (BNMP)	1,377 t/y
Sea Grasses	0.83 t/ha/y	135 ha (Experts, 2012)	112 t/y
Mangroves	1.39 t/ha/y	300 ha (Imares, 2012)	417 t/y
Total without avoided emissions			119,647 t/y
Dead mangroves Degraded mangroves	-70 t/ha/y	3 ha 116 ha	-210 t/y - 8,120 t/y
Total with avoided emissions			**111,318 t/y**

5.6 Conclusion/ discussion

This desk study has made a rough attempt to estimate the carbon sequestration value of the main ecosystems of Bonaire. Based on carbon market prices at the time of research, this value was estimated at $1,340,000 per year. Clearly, it matters greatly what type of per unit carbon value is applied. For example, when the social cost value of Tol (2008) of US$127 per ton of carbon would have been applied, the climate regulation value of the ecosystems of Bonaire would be substantially larger. We limit this valuation study to the market value only because we believe that it has the most practical significance to policy makers. After all, this is the amount that Bonaire's ecosystems might yield on the carbon market.

At the moment, however this is still impossible, since there is only a semi-functional carbon market for forests (REDD), not and for coral reefs or salinas. In addition, it might be that future climate negotiations decide to drastically alter the price of carbon. On the one hand, several NGO's, such as Greenpeace, advocate carbon prices about ten times as high as the $12 assumed here, that would be more effective in curbing energy usage. On the other hand, the economic crisis may reduce the price of carbon to even lower levels.

Other uncertainties regarding the current carbon value of ecosystems of Bonaire are caused by the potential positive feedback loops in the carbon balance. When temperatures reach critical points, the oceans might turn from a carbon sink into a carbon source. Increased CO_2 concentrations in sea water also contribute to coral bleaching. It is though that global warming of only a couple degrees Celsius would be enough to kill the coral reefs, turning them into carbon sources. These feedback loops were not taken into account in this study.

Even though there is a necessity for further research in this field to reduce the level of uncertainty, we think that the economic value of natural environments on Bonaire are clearly demonstrated by this study, especially the carbon storage in mangrove soils which makes up 70% of the total value. Therefore, it is justified to incorporate this value category in the Total Economic Value of nature on Bonaire, be it with the necessary caution.

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6 Pollination by bats

Jenny Möykkymäki, Laurean Dekker and Richa Nanne

6.1 Introduction

The island of Bonaire is a fauna and flora rich and beautiful attraction in the Caribbean region. Pollination, especially by bats, plays an important role in preventing the loss of biodiversity on this beautiful island: bats pollinate different fruits, aesthetic plants and especially cacti, and the dependence between the cacti flower and bats is recognised as the most important link in pollination on Bonaire. This strong link is based on the principle that the cacti flowers offer food for bats during the mating season. So without cacti there would be no bats and without bats there would be no pollination of other plant species.

This mutual relation and the economic value of pollination are connected strongly to the amount of tourists coming to the island. Right now the economy of Bonaire is growing fast due to the increasing number of tourists visiting the island. Tourists can have a strong impact on pollination. There are more than 3000 caves on the island and some of them are home to one or more of 4 different, threatened bat species. These bat species, including the pollinating species, set high standards to the environment they live in (e.g. temperature and humidity). This means that the bats can only survive in some of these caves. When tourists are visiting the caves of Bonaire they can disrupt the bat population which is sensitive to environmental changes.

The aim of this desk study is to give more insight in the economic value of the ecosystem service of pollination by bats.[6] Due to limited availability of data and time, the study will not generate an actual economic value of pollination. Yet, by describing the possible links between pollination and the economy of Bonaire, this study adds value and provides a solid foundation for an actual economic valuation study.

This Chapter is structured as follows. Section 6.2 describes the model used for analysing the economic value of pollination as well as the relationship between the different components and their mutual interdependencies. The different ecosystems which benefit from pollination will be described, including the relationship between bats and tourists, and tourists and the benefits of the ecosystem. Section 6.3 will give a literature review on the valuation methods and Section 6.4 will be an attempt at valuing pollination on Bonaire. This chapter also defines limitations and uncertainties which influence this study. Chapter 6 will attempt to describe different scenarios and in the final chapter, recommendations will be proposed.

6.2 Background

A conceptual framework has been developed to model the interaction between pollinating bats and the economy of Bonaire. This framework is represented in Figure 6.1. This scheme is meant to show the complexity of the mutual influence of the different ecological and economic components. The red arrows represent the main line of reasoning of the study. The thick black arrow represents the interdependent relation

[6] Although the focus of this study is on the role of bats in pollination, a larger share of pollination on Bonaire is performed by birds and insects (i.e. bees, wasps and hummingbirds).

between cacti and bats. The thin black arrows represent actual dependencies, yet due to time constraints and the specific focus of this study, these relationships have not been quantified nor valued in economic terms.

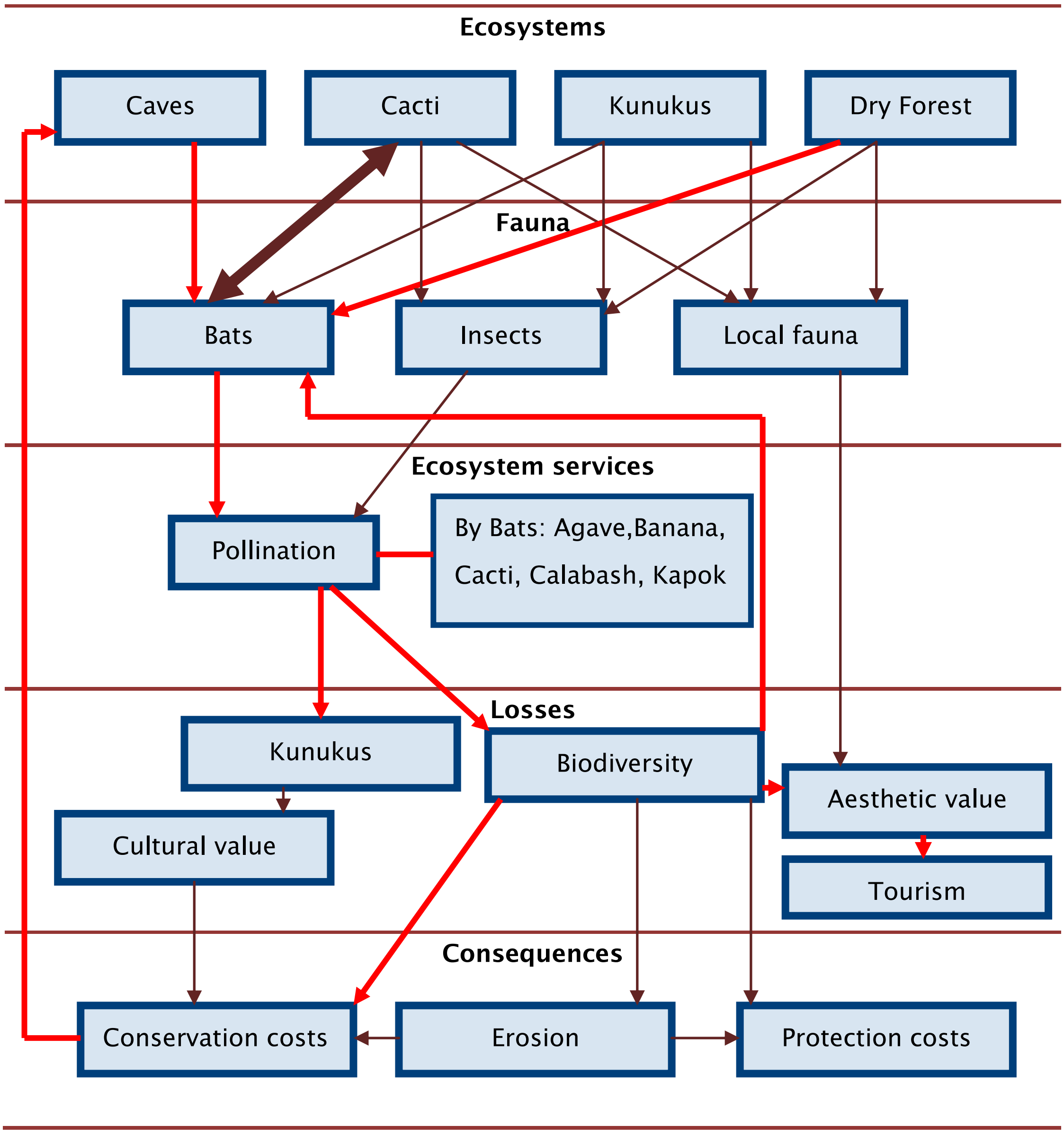

Figure 6.1 Analytical framework showing the relationship between pollinating bats and the economy of Bonaire

Some bat species play an important role as pollinators, they have adapted to eating nectar by having extended tongues and snouts. About 38 bat species worldwide feed on nectar, fruit pulp and pollen, providing specific plant species of pollen (fertilization) and disperse their seeds. Bat families which pollinate flowers are *Pteropodidae* and *Phyllostomidae* bats (family names) (Kunz *et al.*, 2011). The *Pteropodidae* family is not present at Bonaire. The *Phyllostomidae* has two subfamilies, the *Glossophaginae* and the *Stenodermatinae*, the latter one is also not present on Bonaire. The *Glossophaginae* subfamily contains different species; one of them is the *Glossophaga longirostris* or long tongued bat which feeds on nectar, pollen and fruit. This bat species is also specialized in the pollination of the Yatu (*Stenocereus griseus*), one of the three columnar cacti of Bonaire (Table 6.1). The long tongued bat also pollinates the calabash, the flowers of the kapok tree and the banana plant. The *Leptonycteris curasoae*, or lesser long-nosed bat also has a pollinating function, this species also pollinates banana plants, kapok, calabash and the agave tree. The lesser long-nosed bat is also specialized in pollinating the *Kadushi* which is, just as the *Yatu*, a columnar cactus species. These bat species do not only feed on fruit and nectar but also, incidentally, on insects which are attracted to these plant species (*Stinapa* Bonaire National Park Foundation, 2011).

Table 6.1 Pollination of different plant species by bats specifically.

Bat species	Pollination
Glossophaga longirostris (Long-tongued bat)	*Stenocereus griseus* (Yatu), *Ceiba pentandra* (Kapok), *Musa spp.* (Banana), *Crescentia crujete* (Calabash).
Leptonycteris curasoae (Lesser long-nosed bat)	*Subpilocereus repandus* (Kadushi), *Agave vivipara and Agave Cocuy* (Agave), *Crescentia crujete* (Calabash), *Ceiba pentandra* (Kapok), *Musa spp.* (Banana).

Source: Stinapa Bonaire National park Foundation, 2011.

The relation between bats and the Yatu and Kadushi is interdependent which means that these bats are the only species which pollinate this cacti species, making the cacti dependent on the bats. On the other hand, the cacti flower when bats are in the mating season, providing food and, in that way, making the bats dependent on them (Petit, 1997).

This relationship is the most important link between bats and biodiversity, because without cacti there will not be bats and without bats there will be no pollination of other species. Some *Stenocereus* species (yatu) are grown commercially for the fruit they provide. Furthermore, the pollination of this cactus is of ecological importance because this is a keystone species (the ecological impact of this species exceeds their biomass) in dry/arid neo-tropical habitats (Kunz *et al.*, 2011). The columnar cacti on Bonaire are also important during the dry season because they provide essential nutrients other species need to survive during this period (Petit, 1995). Losing the cacti means losing a food source for other fruit eating animals during the dry season which leads to a loss in fauna (Petit, 2001) which is grouped under biodiversity.

Fibres from the fruit of the *Ceiba pentandra* (kapok tree) are used to make kapok, this tree also relies on bats for pollination. The ecological role bats provide for wild plant species is maintaining the genetic diversity among these species, because they disperse seeds and pollen over long distances. This holds especially true for the lesser long-nosed bat which has a large foraging area and disperses the seeds and pollen of the *Kadushi* over the entire area. The *Phyllostomidae* family (of which the long-tongued bat is a subspecies) forage in continued forest areas as well as in forest fragments. This means that this bat species genetically connects fragmented plant populations. The long-tongued bat also disperses pollen between both individual kapok trees and trees in continued forests. Fruit eating bats can carry their food 100-250 m from the tree they got it from and eat from several trees during foraging. *Phyllostomidae* bat species are known to eat seeds from pioneer community plants species, which are the first species occurring in an area which undergoes primary ecological succession. During their flight they defecate the seeds above open areas where the seeds start to grow and new forests can be established.

Pollinating bat species migrate between different types of landscapes. This behaviour depends on seasonal fluctuations and food availability. The lesser long-nosed bat (in Mexico) is known to spend the winter period in dry forests where they mate. While being there they feed on the flowers and fruits this ecosystem provides. In the spring the female bats migrate to a whole other type of ecosystem, the dessert, where they feed on the flowers and seeds of columnar cacti. During this migration they travel more than a 1,000 km. At the end of summer the females and their young migrate inland where they feed on agaves. The movement of this bat species is important for the survival of the plants they feed on. Especially bats living on islands are sensitive for environmental degradation because the different types of ecosystems they migrate through have a limited surface (Kunz *et al.*, 2011).

While bats provide a lot of pollination to useful fruits and aesthetic plants, especially in kunuku's bees and hummingbird provide a lot of pollination for flowers. For example, flowers from the *Gesneriaceae* family are generally pollinated by hummingbirds, some by bats and least by bees (Martén-Rodríguez, 2009). Just like there are cacti that have evolved to feed the bats, and flowers of the *Gesneriaceae* family to feed hummingbirds, there are also flowering plants that depend on bees and insects. Because all these pollinators contribute to Bonaire's landscape, their value will be combined into one.

6.3 Methodology

The main focus of this study is on the valuation of the aesthetic value of pollination by bats. To do this, a link between aesthetic value and the monetary value has to be specified of which the most plausible is tourism. Tourists and eco-tourists are generally attracted to "unspoiled scenery, unique environments" (Heal, 1995) which, according to the Cambridge dictionary, is what aesthetic entails. To give a more precise definition: aesthetic means "relating to the enjoyment or study of beauty". The purpose of this section is to give insight in the different valuation methods used in scientific literature to value pollination. This literature is based on cases from other countries than Bonaire and therefore may deal with different variables than is the case in Bonaire. The pollination by bats has a market service (the price of fruit) as well as a non-market service (the price of biodiversity and aesthetic values). In line with this distinction, three values are considered: crop values, cultural and recreational values and non use values.

Market value

The report of Kunz (2011) describes different valuation methods used to value 448 bat dependent market products which can be divided into different categories like timber and other wood products (23%), food and drinks (19%), medicines (15%), and other products like dyes, fibre, animal fodder, ornamental plants and fuel wood. The fibre extracted from the kapok tree is estimated to have a total value of $4.5 million but there are a lot of other inputs than just pollination by bats and insects, even though they play a role in the production process of this fibre. Pollination by different kinds of animal species, including bats, also plays an important role in the production of crops. 46 out of a 100 crops depend, in different degrees, on pollination. In total 49% of the world's crop production is dependent on pollination. Using the market value of the different types of crops, the total value of this worldwide crop pollination is estimated at $200 billion in 2005.

Despite these substantial values of pollination, the influence of bats on this particular estimate is said to be relatively small. In Mexico one study was carried out a valuation study using the replacement costs estimating what would happen if bats disappeared and crops would have to be protected against insects by using pesticides. This research included 101 farmers which had to pay $19 for pesticides per hectare to protect their crops, which has a total economic value of $1.2 million. The report of Gallai (2009) describes the effect of a worldwide decline of insect pollinators. The method used is a bio-economic approach which contains the dependence ratio on insect pollination for 100 crops used for human consumption. The total value worldwide of pollination was estimated at around €153 billion.

The rate of vulnerability for pollination loss for the worldwide agricultural production for human consumption is 9.5% (see Table 6.2). The loss of food and vegetables is estimated at an economic value of €50 billion for each category. The economic loss of oilseed crops is estimated at about €39 billion. Another important outcome of this research is that crops which are dependent on pollination have a higher economic value than crops that are not dependent on pollination. For example the economic value of fruits is €452 per tonne and for sugar cane it is around €150 per tonne.

Table 6.2 Vulnerability of different crops as a result of pollination loss from insects

Crop category	Average value of a production unit (€ per metric ton)	Total production economic value (10^9€)	Insect pollination economic value (10^9€)	Rate of vulnerability (%)
Stimulant crops	1225	19	7.0	39.0
Nuts	1269	13	4.2	31.0
Fruits	452	219	50.6	23.1
Edible oil crops	385	214	39.0	16.3
Vegetables	468	418	50.9	12.2
Pulse	515	24	1.0	4.3
Spices	1003	1	0.2	2.7
Cereals	139	312	0.0	0.0
Sugar crops	177	268	0.0	0.0
Roots and tubers	137	98	0.0	0.0
All categories		1618	152.9	9.5

Source: Gallai *et al.*, 2009

Cultural services

Nowadays, bat watching is a growing recreational activity, although perhaps not as widely practiced as bird or whale watching. Nightly cave excursions play a major role in providing cultural services like bat viewing. During the daytime these caves serve as hiding places for bats but are also a place where their offspring is born. Not every cave is suitable for bats. An individual's willingness to pay to view bats can be referred to small fees that many sites charge per visitor. The fees range from $5 to $12. (Kunz *et al.* 2011)

On Bonaire bat viewing is mainly part of caving activities. On average, the caving experience tour costs $50 dollars per person. Based on the Kunz *et al.* article, it could be estimated that part of the fee, that involves bats, would be around $10 dollars. For the local communities there is not only the benefit from tourism-generated income but the aesthetic value of the caves and the plants pollinated by bats should also be taken into account. Caving and bat-related tourism are an emotional issue for Bonaire residents who see an increase in the demand for bat viewing; an activity which represents a risk to their fragile environments. Caving tourism provides an incentive to protect wildlife and habitat. Consequently, bat tourism has enormous potential to conserve bat populations while providing social and economic benefits to the people in host communities.

Non-market value

Various studies are relevant a basis for the economic valuation of the non-market value of pollinating bats. The report of Fleischer and Tsur (n.d.) describes how to value agricultural landscapes through contingent valuation methods. Boyer and Polasky (2004) describes different studies and methods to value urban wetlands which are based on “Hedonic pricing” in which they calculated how a change in size or type of a wetland influences the market price of nearby houses (holding the other characteristics of the house constant). Boyer and Polansky are also record the travel costs method in their overview, which values the landscape on the basis of the number of trips to wetlands and the price of these trips. Estimating the non-marked value can also be done by using production methods which focuses on the value of economic productivity of this ecosystem. As described earlier in the Chapter, the replacement cost is another method used to value pollination.

6.4 Results

The focus of this section is on the role the value of pollination for fruits and fibres[7]. In this analysis, pollination of the different cacti is disregarded because cacti are aesthetic and ecological of nature, which makes these plant species harder to value. Because people consume fruit, they have a market value, which will be used to value pollination by bats on Bonaire. Unfortunately, this section will not generate an actual value due to the fact a lack of information. It is hard to find local prices for these products and there was no information on the amount of these products consumed on Bonaire. Products growing in kunukus (like bananas) are probably used for private consumption. To make an estimation of the market price of products, which are dependent on pollination, fieldwork has to be done on Bonaire. By doing fieldwork local market prices, which products are used for private and public consumption and in what amount they are consumed could be gathered.[8] The results that can be presented refer to the physical dependencies of the various crops that are dependent on pollination.

Agave/century plant

The pollination of agave and different cacti has direct benefits for the inhabitants of Bonaire due to their ecological value. The scientific name of the agave species growing on Bonaire is *Agave Vivipara* and *Agave Cocuy*, its local name is “century plant”. This agave species has (just as the cacti at the island) the property to store water in its leaves and stem (Stinapa Bonaire National park Foundation at, washingtonparkbonaire.org., n.d. para. 4) but it does not provide alcoholic drinks or sisal like *Agave sisalana* and *Agave tequilana*. The most important non-use service of the century plant is that it provides nectar for insects and bats on the island. Many agave species are conspicuous species of dry upland ecosystems like dry forests.

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7 Due to the high level of uncertainty with regard to the impact of reduced pollination on tourism, this value category has not been estimated specifically. The importance of terrestrial ecosystems for the tourism industry will however be valued in the Tourist study, which is part of the overall Bonaire TEEB-study (Schep et al. 2012).

8 The fruit and vegetable market on Bonaire was estimated to trade a volume of approximately US$10,000 per year.

Insects also pollinate the agave, which also holds for banana trees. Moths and bats are the most important pollinators of agave because they touch the parts of the plant, which are responsible for reproduction (Arizaga *et al*., 2000).

Banana

Musa species (banana and plantain) belong to the Musaceae, known simply as the banana family. Musa is important not only for fruit production, but the genus has provided man with food, clothing, tools and shelter since the dawn of recorded history. Musa fruits are variable in size, shape, and colour. They are generally elongate-cylindrical and the skin is silver, yellow, green or red in colour. It is grown in 130 countries worldwide, on 11 million acres. Worldwide, the average yield is about 1.56 kg/m^2. As stated in the earlier column, banana is also pollinated by insects and bats (Nelson *et al.* 2006). The bananas on Bonaire are growing in kunukus and are used for private consumption making it difficult to put a market value on this species.

Kapok

Ceiba pentandra, the silk-cotton or kapok tree is an emergent, fast growing tree species with a pan-tropical distribution. It is a tree of the Malvaceae family which came from Africa, South America, the Caribbean and tropical Asia. In Africa it is the largest existing tree, there the tree can reach the height of 60-70 meters and has a sturdy gray trunk of up to three meters. The trunk and many of the larger branches are usually covered with large, robust, simple thorns. The long green fruits are capsules that are bent downward. They are brown when ripe. Adult trees produce several hundred 15 cm long seedpods. The pods contain seeds surrounded by a soft, yellowish fibre that is a mixture of lignin and cellulose. Oil is pressed from the seeds for use in the kitchen, making soap or as fertilizer. The bark is used in traditional medicine to treat headaches or type II diabetes, as an aphrodisiac and diuretic. Kapok trees are pollinated by a wide range of nocturnal (e.g. bats) and diurnal (bees, wasps, hummingbirds) animals, but only bats play a relevant role promoting cross-pollination. (Gribel *et al.* 1998)

Calabash

The calabash (*Lagenaria siceraria)*, also known as bottle gourd, is a bottle shaped fruit. It can be eaten as a vegetable or be dried and used as a music instrument, bottle, utensil or any other use one can come up with. The calabash does have some medicinal uses, but not that many (PFAF, 2011). Its value stems from the equivalent fabricated good. For example, one calabash can serve as two plates, or as a bottle, and thus can be equivalent to the price of such items. Because the price of these items differ from country to country, fluctuate with the market and is also dependent on the quality of the item, putting even a slightly accurate price on this fruit is difficult.

6.5 Conclusion

The island of Bonaire is a fauna and flora rich and beautiful attraction in the Caribbean. By supporting fruit growth and aesthetic values, bats plays an important role in preserving high levels of biodiversity on Bonaire. This study made an attempt to give more insight in the importance pollination by bats for the island. Due to limited availability of data and time, the study will not generate an actual economic value of pollination. Yet, by describing the possible links between pollination and the economy of Bonaire, this study adds value and provides a solid foundation for an actual economic valuation study in the future. Despite of the lack of a concrete economic value, the evidence provide support the notion of conservation of the bats of Bonaire their natural habitat (i.e. caves). Both economic and cultural reasons have been identified to support this conclusion.

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7 Coastal water quality

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7.1 Introduction

Land-based activities such as coastal development and pollution are degrading coastal water quality in Bonaire (DME Slijkerman *et al.*, 2011). To avoid further degradation, investment is being undertaken to create appropriate facilities for treating sewage and improving water quality. The aim of these measures is to protect the pristine ecosystems of Bonaire. Coastal water quality plays an important role in this regard and it is therefore critical to value it in order to highlight the importance of this ecosystem service and to ensure it is maintained.

Activities that threaten the aesthetic value of coastal water quality are considered undesirable by tourists (Burke and Maidens, 2004). This is a significant reason to appraise the extent to which water quality degradation may cause a reduction in tourism on Bonaire. Surface water with good quality means the provision of healthy water with good visibility for swimmers and boaters. Also in the estuarine waters, water salinity correlates with recreational fishing species abundance. Therefore, water quality improvement will positively impact various recreational activities. Cleaner waters are more swimmable, fishable, and improve reef health and fish population and catch rates (Boyd & Wainger, 2003). The maintenance of these benefits requires better regulation and management of local anthropogenic activities, which affect fisheries and water quality (CARSEA, 2007).

Wetlands filter freshwater runoff and increase the quantity of stream flow that is filtered through aquifers to enhance the health of species dependent on surface waters. Through these processes, wetland ecosystems influence coastal water quality directly and indirectly. The valuation of these ecosystems and their contributions to coastal water quality is essential in providing a platform on which to base future policies. Policymakers must understand the value of coastal water quality to accurately identify the tradeoffs between maintaining the Bonaire coast in undisturbed state and continuing with coastal development. This is in line with the notion that technological innovations have the capacity to substitute ecosystem services and it is imperative to address the tradeoffs in choosing between the two (ICSU-UNESCO-UNU, 2008).

Water quality is defined as the chemical, physical, and biological characteristics of water, a measure of its condition relative to the requirements for biotic species or to humans (Johnson, 2009)[9]. This study is only interested in “coastal water quality” for Bonaire’s water, which extends 12 nautical miles from the coast (UN Convention, Law of the Sea). Due to data and time constraints, water quality with regards to drinking water or groundwater will not be addressed in this study. Coastal water quality service is a component of both option value and bequest value. It does not offer direct benefit for human well-being, but rather the value of satisfaction from preserving a natural environment for flora and fauna, and future generations. However, coastal water

[9] Several articles have suggested water quality parameters: (1) Orth *et al.* (2006) proposed chlorophyll load and turbidity as relevant water quality attributes. (2) European Environmental Agency proposed nutrients in transition, coastal, and marine waters as indicators(Chevassus-au-Louis, 2009). (3) DME Slijkerman *et al.* (2011) proposed water temperature, conductivity (salinity), and acid level (pH). And (4) For the sake of this study, visibility is a main parameter to measure water quality.

quality also has a direct impact on biodiversity, which in the end provides use value in the form of tourism and fisheries. From this viewpoint, it is easier to economically value water quality services.

The main aim of this study is address the following research question: “What functions and value do the Bonaire ecosystems of sea grasses, mangroves, and saliñas contribute to providing coastal water quality service?”

This Chapter will continue with a literature review describing other studies that valued the water quality of ecosystems in several countries. It will give a brief introduction of the valuation methods used in these studies: contingent value method, travel cost, and benefit transfer. Next, Chapter 3 will describe the methodology or framework utilized to determine water quality valuation. This section will explain the steps taken to determine which economic valuations this study uses. Subsequently, Chapter 4 elaborates on the ecosystems in Bonaire that contribute in provisioning water quality services. Chapter 5 contains a valuation of these ecosystems based on their provision of coastal water quality services. Chapter 6 will finish with recommendations for future studies and conclusions for this report.

7.2 Literature

The valuation of coastal water quality has a significant body of previous research. The main valuation methods used in this research include travel cost models, contingent valuation, contingent behaviour and real behaviour (combined stated preference and revealed preference), and benefit transfer. This section will outline these valuation methods, the most relevant research using these methods, the location of the studies, the strengths versus weaknesses (limitations) of each approach, and (if relevant) the findings of each study.

Travel costs

Travel cost estimation methods are used to estimate economic use values for ecosystems or sites associated with recreation. The most relevant use to water quality on Bonaire is the economic value associated with a change in water quality on the island. Travel cost models use the cost of travel as an indication of a persons’ willingness to pay for access to the resource, and thus determine an economic value from these prices.

While travel cost models are relatively inexpensive, they fail to account for non-use values, and any values associated with water quality that doesn’t specifically regard recreation. In literature, using the travel cost method in isolation to estimate the value of water quality is rare. Several studies were performed in the 1980’s (Smith and Desvousges, 1985, Desvouges *et al.*, 1983), but most recent studies involving travel costs do not seem to address water quality. Because of these limitations, travel costs are often combined with other forms of valuation (especially contingent valuation) in order to arrive at a more accurate valuation (Travel Cost Method, n.d.).

Contingent valuation

Contingent valuation has been used to estimate water quality values by using Willingness to Pay (WTP) and Stated Preference (SP) models. Stated preference models ask participants to choose between several scenarios: specifically, differing levels of water quality improvements (or deterioration) in relation to a ‘status quo’ scenario (Eggert and Ollson, 2004). Stated Preference models are often used in coordination with Willingness to Pay models, which use questionnaires to evaluate participants' willingness to pay for specified changes in given scenarios.

Many studies regarding water quality have been performed using contingent valuation, including a study done in France (Le Goffe & Gerber, 1994), a study covering two coastal areas in Costa Rica (Barton, 2002) and a study in Scotland (Hanley, 2002). However, by far the most relevant contingent valuation study was performed on Bonaire and regarded coral reef health (of which water quality is a significant aspect). Parsons and Thur (2007) interviewed 211 US tourists who have previously visited Bonaire. They asked a series of questions regarding different reef quality scenarios with regards to visibility, species diversity, and coral cover. "Per diver annual values ranged from $45 for the modest declines in quality to about $192 for extreme declines in quality. These translate to asset values for the coral reef system of $50 to $500 million for recreational SCUBA diving – depending on the level of decline, assumed rate of discount, and expected growth in diving" (Parsons and Thur, 2007). While this valuation includes water quality in its valuation, it is very difficult to isolate its contribution to the overall results. In addition, the results do not consider all tourism (only SCUBA divers), local use-values, other recreational values, or non-use values.

Contingent and real behaviour combination

A combination of contingent and real behaviour can offer a more accurate estimate of valuation than either method independently, considering that a person's stated preferences does not always align with his/her actions (Hanley *et al.*, 2002). This method estimates the economic impact of water quality improvement by combining both stated and revealed preferences of visitors to an area of study. There are two distinct approaches to combine these methods to create an accurate valuation: Random Utility Models and Contingent Behaviour. Random Utility Models use choice experiments, involving questions which offer choice alternatives. These studies seem most appropriate for studies focusing on recreational aspects of a location, where environmental quality creates substitution effects across a number of sites. Contingent Behaviour involves using pooled or panel data models to compare stated preference versus actual behaviour (*ibid.*).

The random utility model approach to combining contingent and real behaviour was performed in Alberta, Canada in regards to water-based recreational activities by Adamowicz, *et al.* in 1994. This study has many limitations in regards to our report: it is expensive, out-dated, does not apply to coastal water quality, and involves questions of water improvement, not deterioration. Despite these limitations, this method could be an appropriate approach to valuing water quality deterioration or maintenance on Bonaire with regards to tourism, due to its focus on determining the relationship between environmental quality changes and visitors' choices to substitute recreational sites (Adamowicz *et al.*, 1994).

The Contingent Behaviour approach was used by Hanley *et al.* in 2002 to study coastal water quality in Scotland. The authors defend their methodological approach by explaining that: "(a) we wish to focus on the value of improvements, rather than the value of site attributes and since (b) we find that most of the effects of a change in environmental quality come about as a change in the total number of visits to all beaches in the area, rather than a re-allocation of visits across sites (Hanley *et al.*, 2002). This study could be of particular relevance when trying to value the contribution of local tourism on island, since many locals do not have choice alternatives for recreation (i.e. other islands).

Benefit transfer

"Benefit transfer involves the application of primary non-market valuation estimates to a secondary setting for which the original study was not expressly designed" (Barton, 2002). Benefit transfer is a preferred method of valuation because it can be performed quickly and cheaply. Benefit transfer has three separate approaches: "(i) transfer of fixed values or unadjusted mean value estimates, (ii) value estimator models or benefit function transfer, and (iii) expert judgment methods" (*ibid.*). The accuracy of valuation using all three of these methods is thoroughly analyzed in literature (*ibid.*) (Bergland *et al.*, 2002), motivated in part by the study by Costanza *et al.* (1997) which was plagued with transfer value errors.

Challenges for accurate benefit transfer include the transferability of the data from one site to another, the application of the most appropriate method of transfer (listed above), as well as the accuracy of the primary data used for the transfer. This is of particular concern for Bonaire, because it is such a unique island. A study by Brouwer in 2011 evaluating benefit transfers indicates that the method has recorded transfer errors as high as 56% for unadjusted unit value transfer, and an astonishing (and unacceptable) 475% for adjusted value transfer.

Comparative studies

Various studies have been run in attempt to value water quality. These studies might give idea on how people approach this valuation.

- Meta analysis on 25 studies by Brander *et al.* (2006) found the average value of water quality is around $730,000 per km square.
- In Stockholm archipelago, €6–€54 million per year benefit are obtained from improved water quality, fisheries catch increasing €19 million per year. In reverse, 30-40% loss of juveniles related to degraded water quality costs €6 - €8 million per year for fisheries. In another case, camping ground owners have to remove dead red algae, costing €8,119 per km annually (Braat *et al.*, 2007).
- In New York City, United States, to deliver safe water without investing $6 billion water filtration plant the city chose to use natural water regulation services of largely undeveloped watersheds, investing $100 million per year for easements (De Groot *et al.*, 2006).
- One method of damage cost avoided was employed in Catawaba River, United States. In 1998, protecting water quality in the 360-kilometer river for five years was around $346 million (Millennium Ecosystem Assessment, 2005).

More details on the valuation of ecosystem functions with regards to water quality on Bonaire will be explained in the Methodologies section below.

7.3 Methodology

It has been mentioned in literature (Bateman, 2010) that in ecosystem valuation, one has to bridge the services provided by ecosystems with benefits reaped by human beings. Figure 7.1 explains the methodological approach taken in this report. The main ecosystems providing water quality related ecosystem services are sea grasses, salt marshes and sea grass beds. The services provided by each of these ecosystems are described in the following.

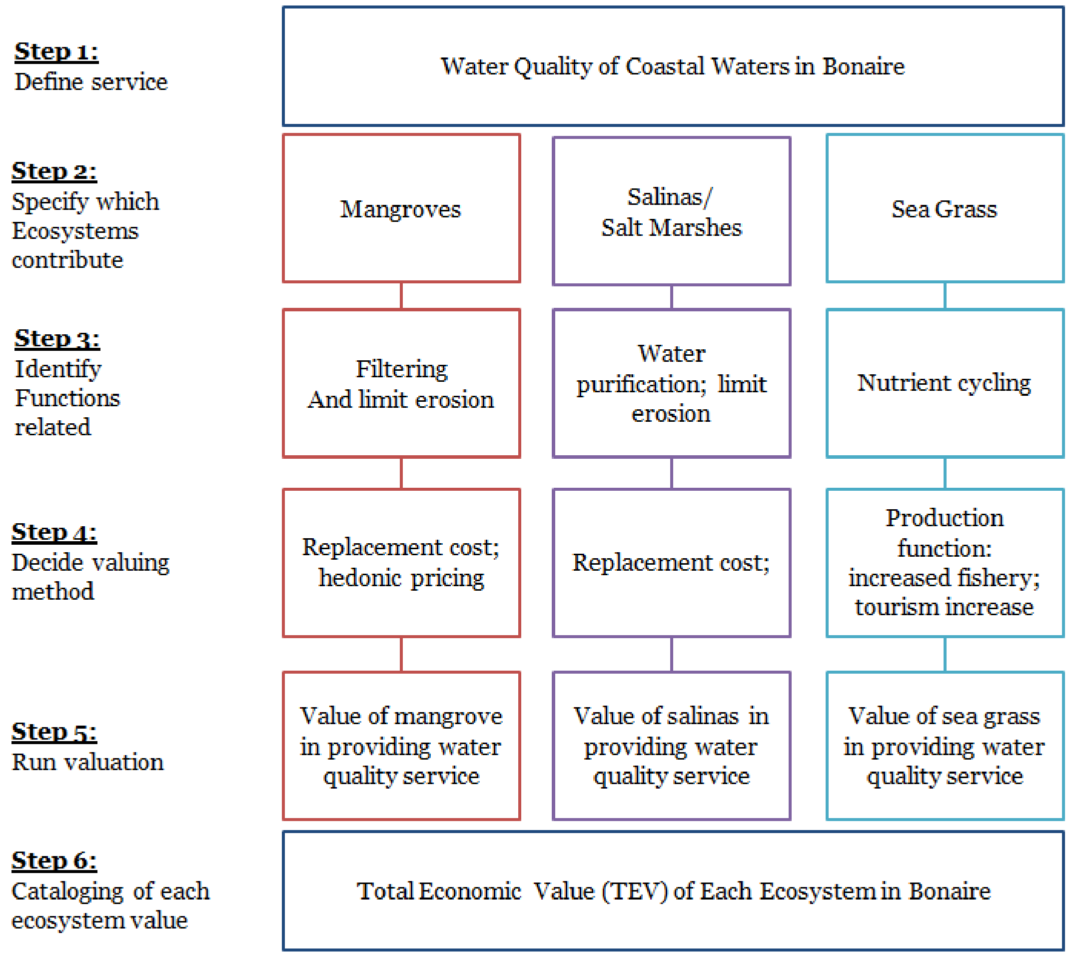

Figure 7.1 Steps in water quality assessment and valuation in Bonaire

Sea grasses

Sea grasses are flowering plants in the coastal ocean whose appearance resembles grassland in terrestrial environment, hence the name. They belong to the four plant families of *Cymodoceaceae, Hydrocharitaceae, Posidoniaceae,* or *Zosteraceae.* The sea grasses found in Bonaire are mostly found in Lac Bay, and commonly named “turtle grass” (with the taxonomic name *Thalassia testudinum,* from the *Hydrocharitaceae* family) (Nagelkerken, 2000) (Dineen, 2001). Their distribution extends from Florida through the Gulf of Mexico, Bermuda, the West Indies, Central America, and Venezuela, including the island of Bonaire (*ibid.*). Also, one might find manatee grasses (*Syringodium filiforme*) in Bonaire (STINAPA, n.d.).

Sea grass ecosystems are considered some of the most enabling ecosystems due to their key functions in the saline water environment. They are identified in: the regulation of water flow and current, nutrient cycling, food web structures (as a primary producer), coastal protection, and oxygen production. To maintain focus on the subject of water quality, this report only assesses sea grasses’ value in promoting nutrient cycling and oxygen production (through photosynthesis).

With their structure and the anatomy of their leaves, rhizomes, and roots, sea grasses are able to “control” coastline currents and waves, which effectively trap and reserve sediments and nutrients. Ultimately, these functions enable sea grasses to filter nutrient inputs to coastal waters (Orth *et al.*, 2006). The nutrient cycling function of sea grasses is performed through the fixing of nitrogen by bacterias which live on the grasses: *rhizospheres* on sea grass roots or *epiphytes* around leaves and stems (Harborne, 2006). Sea grasses maintain water quality by interrupting freshwater discharge and acting as a sink for materials and pollutants. Subsequently, they promote coral reefs growth and improve the water environment, which ultimately favours recreational activities such as SCUBA diving (Moberg, 1999).

Threats: Sea grasses are pressured by epyphates eutrophication (DME Slijkerman, *et al.*, 2011), erosion from coastal development, overfishing and overtourism (Poussart *et al.*, 2008), and could be degraded by oil spill (Boyd, 2010). Climatological events have been identified as the pressures in tropical regions like Bonaire for raising the sea level, as depth in water is critical for sea grass survival (Orth *et al.*, 2006). Around Lac bay, heavy tourism also accounts for major threats since swimmers, snorkelers, and windsurfers disturb the sea grass beds by continually trampling them, sometimes damaging them beyond regrowth (STINAPA, n.d.). This will harm tourism potential as sea grass beds and their biological filter systems create the azure-blue coloured water which attracts tourists (*ibid.*). The loss of sea grass also damages fisheries industries, as DME Slijkerman found (2011). The harm imposed by degrading or damaged sea grasses to tourism and fisheries is associated with the degradation of water quality, which is caused by excessive nutrient and sediment loadings (Poussart *et al.*, 2008).

Mangroves

Mangroves are trees and shrubs of the genera *Rhizophora*, *Brugiera*, *Sonneratia* and *Avicennia*. There are about 70 different species of Mangroves around the world growing in tropical, coastal areas. Mangroves are unique in their ability to convert salt water into fresh water through reverse osmosis, allowing these plants to survive in a diverse range of water ranging from brackish to pure sea water.

The island of Bonaire hosts two species of Mangroves: the red mangrove (*Rhizophora mangle*) and the black mangrove (*Avicennia germinans*). The entirety of Mangrove forest on Bonaire is situated in a wide lagoon called Het Lac (STINAPA - Bonaire National Marine Park. (n.d.) on the windward side of the island. Mangroves cover an area of 300 hectare of which 3 hectare is dead mangrove and 116 hectare is in a degraded state (Imares, 2012).

Mangroves serve a large number of ecosystem functions, including exporting organic matter to marine environments, shoreline protection from erosion, barriers from storms, nurseries for fish and birds, and maintenance of water quality (Bann, 1997). As this report specifically focuses on Coastal Water quality, only mangrove functions relating to this ecosystem service will be addressed and valued herein.

“Mangroves maintain water quality by extracting nutrients from potentially eutrophic situations and by increasing the limited availability of saline and anaerobic sediments to sequester or detoxify pollutants” (Bann, 1997). They also reduce erosion by slowing water flow, thus maintaining water clarity. Mangrove muds also serve as a sink for trace metals and other chemicals harmful to water quality (Harbison, 1986).

Threats: There are a vast array of anthropogenic activities which threaten Mangrove ecosystems globally. These include clearing, overharvesting, river changes, overfishing, destruction of coral reefs, overfishing, pollution, and climate change. These activities, combined with a lack of understanding of the ecological significance of mangroves (until recently), have lead to a 35 to 50 percent loss of global mangrove stocks (Mangroves, n.d., Barbier *et al.*, 2008).

On Bonaire, "Human influence has undoubtedly strongly reduced the mangrove cover on the island (Teenstra 1977; Haviser 1991)". The main threats to the Lac Mangroves are mostly from river changes, pollution (eutrophication from human and animal waste), overfishing, and sea level rise. (STINAPA - Bonaire National Marine Park, n.d.) River changes threatening the mangroves are caused by the formation of a road through the middle of the island. This has been associated with reduced rainwater run-off to the Lac, thus decreasing the ratio of fresh to salt water in the Mangrove forest (*ibid*). Pollution is being recognized as a problem in Bonaire, contributing to reduced reef and water quality. A study has shown that approximately 114,000 kilograms of nitrogen are released into Bonaire's coastal waters each year, and this number is rising (Zimmo *et al.*, 2004). Sea level rise contributes to Mangrove loss due to a reduction in water pressure, an essential aspect of the Mangroves' ability to convert salt water into fresh water (STINAPA - Bonaire National Marine Park, n.d.). Overfishing in the areas surrounding Het Lac has been reported by RAMSAR. Overfishing has been tentatively linked as a contributor to Mangrove deterioration through foodweb changes.

Saliñas

Saliñas are salt flats or hypersaline lakes located close to the sea and often embedded by estuaries and salt marshes. Saliñas cover about 3% of the island's surface or approximately 8.64 km^2 (Freitas *et* al, 2005). These areas are landlocked with natural openings to the sea blocked by dead corals or beach rocks. However, most of them have access to the open sea by (artificial) channels (Ramsar, 2000). The saliñas have different appearances, some of them are shallow water lakes that are remainders of former lagoons, some exist at the end of valleys and others are areas around the inland bays. Most of them are permanently flooded, have fluctuating salinity levels and consist of sand, loam and clay soils. Other saliñas, in the lower and middle terrace in the south of the island, are only periodically inundated depending on rainfall (De Freitas *et al*, 2005).

The saliñas are considered as valuable wetlands, with a rich biological diversity including sea-grass beds, tropical marine meadow, fish populations and other species such as the brine shrip (Ramsar, 2000; De Meyer and Macrae, 2006). The areas are especially important as a breeding and feeding ground for water birds (Vieira and Bio, 2011). Some important saliñas on Bonaire are Ramsar sites, that are considered as wetlands of international importance (Ramsar, 2000). Protection of these areas is important for the threatened Caribbean flamingo (*phoenicopterus rubber*), a beloved sight and symbol of Bonaire (Buitrago *et al.*, 2010).

Saliñas provide a number of ecosystem functions, such as a habitat function for animals and plants and a storm protection function. Some of the animals in the saliñas are also important for nutrient cycling, such as little crabs and the Dunaliella salina, a type of algae (Buitrago *et al.*, 2010). Most important to water quality is the buffering function served by salinas through the capture of rainwater run-off. The poor vegetation on Bonaire, due mainly to the dry climate and the goats and donkeys that graze there, causes the soil to erode easily, and flows of rainwater take sediments, nutrients and waste with them into the saliñas (Borst and Haas, 2005; Kekem *et al.*, 2006) The saliñas retain the nutrients and sediments from this run-off and partially prevent them from flushing into the oceans where they would pollute the water and cause damage to the corals (Natuurbeleidsplan, 2004; De Meyer and Macrae, 2006; Kekem *et al.* 2006). Some nutrients, such as Phosphorus, and many organic and inorganic pollutants bind to sediments which are retained by the saliñas (Teal, 2001). In 2006 it was estimated that the saliñas took in 11,160 m^3 of water discharge from run-off and prevented approximately 1,390kg N and 600kg P from directly entering the sea water (Kekem *et al*. 2006).

Salt marshes

Salt marshes are mud flats that are vegetated. They exist above sea level in intertidal areas where higher plants grow. The salinity of marshes can vary, depending on the weather, tide and the frequency of flooding. Some of the higher salt marshes can get so saline, due to the evaporation of the water and poor and irregular flooding, that they become salt flats where only salt-resistant algae can grow (Teal, 2001).

While the existence and quantity of salt marsh on Bonaire is unclear from the literature available, it is likely that salt marsh exists on Bonaire since it usually occurs in conjunction with mangroves of which there are a large number on the island (see above). The fact that saliñas are often surrounded by estuaries or salt marshes can also indicate their existence (Vieira and Bio, 2011) and also the IUCN mentions salt marshes on Bonaire, but does not specify the area and might confuse them with saliñas (Petit and Prudent, 2010).

The salt marshes have mostly the same functions as the saliñas (see above) (Teal, 2001; Boorman, 1999). In addition to this, studies have shown that salt marshes perform denitrification (Kaplan *et al*., 1979), decomposition and disposal of waste (Adnitt *et al*., 2005), and the accumulation of nitrogen in the soil (Craft *et al*., 2009). All of these functions affect the water quality of the coast by preventing eutrophication (Teal, 2001).

Threats to saliñas and salt marshes

The threats to salinas and salt marshes are similar and include coastal and inland development, increased sediment loading, tourism, rising sea levels due to climate change (Williams, 2002), possible conversion and dredging of the saliñas by the salt industry (Ramsar, 2000; De Freitas *et al*., 2005). The saliñas on Bonaire enjoy legal protection by both national and international regulation. However, the judicial protection of the areas on the island is insufficient and not structurally controlled (Stinapa, 2010). Complaints about the poor management of some of the saliñas are made, such as construction works that cause problems for the saliña de Vlijt (See e.g. Antilliaans Dagblad, 2010). Construction works and heightening of the land are also recognized as a threat in the 'Evaluation of the Natuurbeleidsplan 1999-2004'. An increased amount of sediment poses a threat because it can prevent flooding, which is necessary to dilute nutrients. It also fills up the saliñas causing them to decrease in size (Kekem *et al*., 2006). Pollutants from all kinds of waste in these run-offs can cause damage to the animals and plants living in the area, making the ecosystem less effective (Borst and De Haas, 2005).

7.4 Results

The results of economic valuation of the above mentioned ecosystem services are reported for each ecosystem in the following sub-sections.

Sea grasses

One way to value the non-marketed services provided by sea grasses is by using production functions to analyze how will people benefit from good water quality. It has been stated that fisheries and tourism are two particular sectors in Bonaire that rely on good coastal water quality. Furthermore, it is easier to value good water quality by examining how it affects fisheries and tourism. This is in line with the discourse that the quality of water is not a final service because water quality is an intermediate good in providing other sectors, such as abundance in fish stocks for fisheries (Boyd & Banzhaf, 2007).

Fish nurseries (and in the end fisheries in general) are sensitive to water quality degradation. Water quality is dependent on wetland and sea grass ecosystems in Bonaire (Boyd & Waigner, 2003). Healthy water quality is also important to support tourism, as tourists in general appreciate cleaner water with better visibility. Based on those notions, the production function valuation method is the most appropriate to appraise water quality services of sea grasses in Bonaire. For this method, there are two approaches. The first is to explore how water quality in Bonaire contributes to increasing economic benefit from fisheries and tourism. The other is to consider how much value from fisheries and tourism would be lost due to degraded water quality.

It has to be emphasized that the values available throughout the literature need to be justified with the total area of sea grass beds in Bonaire. IUCN (2011) performed a study that measures the total area of sea grass beds in Bonaire, which stretches to 2,700 hectares area (27 km^2).

Various studies have valued ecosystem services with regards to tourism and fisheries benefits. For practical reasons, these studies can be used as a benchmark on valuing sea grasses service for water quality in Bonaire. In other words, the valuing method proposed in this report is not purely production function, but also involves benefit transfer method.

- The study in Olango Island, Philippines found the value of coral reefs, sea grass, and mangroves in providing services in fisheries and tourism to be $63,400 per km^2 (Conservation International, 2008).
- Silvestri and Kershaw (2010) reports a global estimation of lagoons and sea grass benefits of around $73,900 per year per km^2.
- In Indonesia, fisheries from good water quality in Wakatobi National Park, Southeast Sulawesi produce around $10,340 per km^2 annually, while eco-tourism produce $1,320 per km^2 (ibid.).
- Fisheries in the reef area of Meso-American Barrier Reef in Belize, Honduras and Mexico returns a benefit of $15,000 to $150,000 per km^2 (ibid.).
- Fisheries in Rekawa, Sri Lanka were valued $1,088 per km^2 per year (ibid.)
- In Matang, Malaysia, fisheries production are valued $250,000 per km^2 per year (ibid.)

Collating from the findings mentioned above, Table 7.1 shows the valuation of sea grasses as they contribute to water quality on Bonaire using direct unit benefit transfer. Three approaches to valuing sea grasses are used in Table 7.1: its impact on fishery, tourism, or both. From the fishery perspective, it is proposed that the value of sea grasses is between $1,088 and $250,000 per km^2. If one upscales (transfers the values from the study site to policy site by adjusting the km^2) this into Bonaire sea grasses, then the fishery production function of sea grasses is between $29,376 and $6,750,000. We acknowledge that the case in Matang, Malaysia, can be considered an outlier and thus can be excluded. Therefore, we conclude that fisheries benefits gained from good water quality in Bonaire is between $29,376 to $405,000.

For tourism production function, only one study is used as a reference, which comes from Wakatobi National Park, Indonesia. According to the data, good water quality contributes to $1,320 per km^2 in tourism. If one upscales this function into Bonaire area, Bonaire sea grasses are valued at $35,640 for the benefit they contribute to tourism.

The last approach that can be used in valuing sea grass is valuing fishery and tourism as a whole. The study on Olango Island, Philippines and the global study by Silvestri and Kershaw give us an estimation between $63,400 to $73,900 per km^2 of sea grass. This mean for maintaining good water quality attributed to sea grasses existence is valued at between $1,711,800 to $1,995,300.

Table 7.1 Various studies on production function method

Fishery and Tourism	**per km square ($)**	**Bonaire (27 km square)**
Olango Island, Philipines	63,400	1,711,800
Global	73,900	1,995,300
Fishery		
Wakatobi National Park, Indonesia	10,340	279,180
Meso-American Barrier Reeves	15,000	405,000
Rekawa, Sri Lanka	1,088	29,376
Matang, Malaysia	250,000	6,750,000
Tourism		
Wakatobi National Park, Indonesia	1,320	35,640

Mangroves

In this section two methods of valuation for mangroves will be explored, unadjusted unit value transfer, and replacement cost. Each approach has limitations which will be outlined below, and in every case the value given will be a *rough estimation* of the value of Mangroves on Bonaire as they relate to water quality.

Unadjusted value transfer

This report will use three values for value transfer. The first is the unadjusted mean value transfer of a meta-analysis of wetland studies from around the world (Brander et al., 2006). The second and third are unadjusted unit value transfers from studies done in Micronesia and Thailand. The results are detailed in Table 7.2, followed by limitations of these value transfers.

There are several general limitations that apply to all of these value transfers. The first is that the adjusted values use the Consumer Price Index (CPI) from the United States Bureau of Labor Statistics. The CPI measures the fluctuations in price level of consumer goods and services purchased by households. This method of adjusting for inflation is a limitation because it assumes that the price levels in the countries where these valuations took place also had the same rates of inflation as the CPI indicates, which is highly unlikely. These value transfers also assume that since the time of valuation, the value of mangroves/hectare has remained the same (i.e. that relative scarcity or a relative increase in use value has not altered their values since the time of the study).

Table 7.2 Various studies on valuing mangroves

Study Location/ Author	Method of Valuation	Estimated Value ($/Ha)	Year of Valuation	$/Ha Adjusted*	Hectares of Mangroves on Bonaire	TEV of Bonaire Mangroves (Adjusted for Inflation)
World Mean Value (Brander et al, 2006)	Collaboration of many methods	$400	1995**	$576	4.6 KM2 = 460 Ha	$264,960
Kosrae, Micronesia (Naylor and Drew)	Direct Use: Market Valuation	$426 - $640	1996	$612 - $921	4.6 KM2 = 460 Ha	$281,520 – $423,660
Surat Thani, Thailand (Sathirathai, 1998)	Direct Use: Market Valuation	$82- $105***	1998	$114 - $146	4.6 KM2 = 460 Ha	$52,440 - $67,160

*Calculations: Adjusted Price = (PIY/EV)/PIN
Where PIY = Price Index in the Year of Valuation, EV = Estimated Value at time of study, and PIN = Price Index Now (August 2011 – the most recent index released). CPI data provided by US Bureau of Labor Statistics (ftp://ftp.bls.gov/pub/special.requests/cpi/cpiai.txt)
**Brander et al adjusted all compiled valuations to 1995 US $
***This study offered a value of $513-$685/Thai Rai. 6.25 Rai = 1 Hectare, so the calculation was simply: $/Ha = ($/Rai)/6.25

Of course, the most glaring limitation of these unadjusted value transfers, inherent to the method, is the assumption that the value of Mangroves per hectare on Bonaire is exactly the same as in the locations of the study. This direct transfer method ignores relative scarcity altogether. Bonaire has significantly fewer mangroves than any of these study areas, and therefore the value of these mangroves should be greater, per hectare, than any of the sites studied. This is due to the theory of decreasing marginal utility value with regards to ecosystems (lecture 09/10/2011, van Beukering). Another limitation with regards to this benefit transfer is that the estimated values for Mangroves on Bonaire are for Total Economic Value (TEV) in the case of Brander *et al.* (2006), and Direct Use value for the other two studies utilized, not the value of Mangroves as they contribute to coastal water quality.

Replacement Cost:

The replacement cost method for valuing an ecosystem service measures the cost of restoring or synthetically replacing an ecosystem service (Balmford *et al.*, 2002). The cost of restoration involves transferring data from other studies around the world that have valued the cost of restoring Mangroves.

Cost of restoration:

Extensive studies estimating the restoration costs of Mangroves around the world have been performed. The estimated price ($/ha) from these studies varies significantly, from $225/ha to $216,000/ha (Lewis, 2001). A major factor in the cost of replacement is the technique used for restoration. Lewis divides these into three categories (listed in ascending order of cost):

- Planting only
- Hydrologic Excavation (with or without planting)
- Excavation or Fill (with or without planting)

The technique of planting is often unsuccessful, and can lead to undesirable results: the replacement of a valuable, in-tact ecosystem (such as sea grass meadows) with mangroves. Hydrologic excavation has seen some success with significant planning, but is usually used to restore mangrove habitats in cases of prior land-use change (i.e. shrimp farming). Excavation or fill is the most expensive technique, and requires moving large amounts of soil. This option is usually only available to ‘developed’ countries, and is unlikely to be considered on Bonaire due to the lack of available soil on such a small island (Lewis, 2001).

A very rough values transfer from global studies suggest that such a restoration could cost anywhere between $103,500 and $99,360,000. This variance is too large to give a meaningful or accurate estimate of restoration costs. The limitations presented by future uncertainties (a lack of data on the method of restoration which might be needed, the degree of deterioration that might occur, the total area which might be involved in restoration) makes this method of valuation too imprecise. This method of valuation also assumes that successful restoration is possible, which may not be the case for an ecosystem as small and specialized as the mangroves on Bonaire. While the low-end estimate is somewhere near the direct value transfer estimates, the high-end value is astronomical. It is unlikely that any merit would be given to such an exaggerated value. Meanwhile, these values suffer from another limitation with regards to our study: the cost of restoration values mangroves total economic value (their contribution to all ecosystem services).

Saliñas

Due to the unknown data on salt marshes it is not possible to attempt a valuation for this ecosystem. Saliñas could potentially be valued in relation to their contribution to coastal water quality if more data or similar studies would be available. There have been a number of studies that have valuated wetlands as a whole for water quality (Brander *et al.*, 2006), and marsh land or salt flats as a whole (WWF, 1986). Unfortunately, a specific study on the valuation of water quality by saliñas has not been performed, and therefore a value transfer is not possible and an estimate value cannot be given.

Another way in which the saliñas contribution to water quality could be valued is by using the replacement cost method. This can be done by estimating the costs of synthetically trapping sediment and removing N and P out of rainwater run-off. This would be accomplished by installing sediment fences on the island that would prevent sediments from flushing into the ocean (UNEP, 2008). This valuation would involve an investigation into how much sediment is being captured by the saliñas, how many fences would be required to replace the salinas, and the costs of the fences, labour, and maintenance.

The function of retaining N and P in the saliñas can possibly be replaced by efficient waste water treatment. Bonaire has recently installed a waste water treatment plant and is planning another one (Kekem *et al.*, 2006). Many data would be necessary for an effective replacement cost valuation, such as the initial instalment costs and the operational costs of a plant for the removal of a similar amount of N and P as the saliñas and labour costs.

7.5 Conclusions

This study has attempted to define the functions and estimate the values to coastal water quality on Bonaire contributed by three key ecosystems. Sea grass, mangroves and saliñas and salt marsh have been defined and their functions that contribute to the ecosystem service of coastal water quality are described in detail.

To establish the importance of maintaining coastal water quality, this report showed clear scientific links between several ecosystems on Bonaire and their reliance on consistent coastal water quality. It has also suggested that coastal water quality is a significant contributor towards tourism and fisheries, both significant economic activities on the island. The report has also outlined that accurate valuation of coastal water quality is essential in order to create a policy platform for protection of this ecosystem service.

Furthermore, this study has attempted a straightforward valuation of these ecosystems' contribution to coastal water quality by using a combination of production function, benefits transfer, and replacement cost valuation methods. The limitations of these valuation attempts are clearly outlined in the "valuation" section, and are so extensive that these values should only be used with great caution. Combining the resulting data into one value for 'coastal water quality on Bonaire' has proven problematic, since the values overlap significantly and a combination would create issues with double-counting. This result emphasizes the difficulties in isolating ecosystem services and functions within the complex, intertwined relationships contributing to coastal water quality. It also demonstrates why most other studies attempting to value water quality have done so by relating its value to tourism, fisheries, or other significant economic impacts, rather than trying to isolate contributing ecosystems and value their contributions individually.

It is clear from this analysis that further scientific data are needed to understand the complex biological relationships involved in maintaining coastal water quality. It is also clear that this data should be combined with more detailed economic analysis of coastal water quality on Bonaire in order to arrive at a more accurate, acceptable estimation of its value. Although it has not offered a total valuation of coastal water quality on Bonaire, this report has clearly outlined the significance of accurate valuation of coastal water quality on Bonaire, and can be used as justification for further studies in this area.

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8 Amenity value

Francielle Lacle, Dario Zambrano and Philip Schols

8.1 Introduction

Many people prefer natural over built environments (van den Berg *et al.*, 2007). Often this preference is manifested in house prices, a summation of structural characteristics and external attributes. The former constitutes aspects such as house size, the number of bathrooms, rooms, etc., while the second consists of a wide range of variables, such as local crime rate, school quality, distance to the coast, beach quality, green areas, and the environmental quality (Brouwer *et al.* 2011). External traits such as the view or proximity to water bodies could supply amenities or disamenities to the residents and have a strong effect on the people's willingness to pay (Jim & Chen 2009, Quah & Tan 1999).

This study aims to estimate the amenity value of nature on Bonaire on account of bringing amenity value on the debate table of decision makers but also for future TEV studies of Bonaire's ecosystems. A hypothesis was developed for the purpose of this study. We test the hypothesis that property values are not only determined by conventional house and neighbourhood characteristics, but also affected by the presence and quality of Bonaire's ecosystems.

This Chapter is structured in line with the step-by-step approach followed to test the hypothesis. Section 8.2 accounts for the first three steps in the analysis, which includes (1) Defining the service; (2) Specifying which ecosystems contribute to this service; and (3) Identifying the functions supporting the relevant services. Section 8.3 involves step (4) which is the selection of the appropriate valuation method. Section 8.4 presents step (5) which is the actual valuation of the amenity value.

8.2 Ecosystems, functions and services

Various techniques, included hedonic pricing, have been used to show that the price of coastal housing units varies with respect to environmental variables and contribute to the amenity value of the property. The hedonic pricing studies demonstrate that the aesthetic value of estuarine and coastal ecosystems may have a substantial economic significance (Ghermandi *et al.*, 2009). Open space, proximity to clean water, scenic vistas, beach colour, presence of tides are cited as primary attractors of residents who own property and live within the coastal fringe (Landry & Hinsley, 2011; Ergin *et al.*, 2006; Jim & Chen, 2009; Roca *et al.*, 2009; Beach, 2002; Dayton *et al.*, 2005). For example, Kauko *et al.* (2003) reviewed that water quality, direct waterfront, proximity to shore and water/shore view contribute to house pricing up to 30% for the first three attributes whereas the contribution of an ocean view is up to 60% of the price.

Figure 8.1depicts the ecosystems in Bonaire and the functions which contribute to the aesthetic and scenic services which this study labels amenity value. It is important to outline the interdependence between marine ecosystems supporting physically other ecosystems (i.e. shoreline and coral reefs supporting mangroves and sea grasses), supporting biota (nursery by mangroves and food source for reefs fishes by sea grasses) or interchanging nutrients (nitrogen from the reef and carbon from sea grasses and mangroves (Moberg & Ronnback, 2003, Harborne *et al.* 2006).

There are several ecosystem functions that contribute to amenity value of the island through aesthetical (e.g. open space leisure, scenic beauty, inspiration for artists, turtle watching, bird watching and hiking); and spiritual services (e.g. spiritual health, security or social belonging) (Nunes *et al.* 2010). First, sea grasses and mangroves contribute to sediment deposition and it maintains the clear water for proliferation of algae in coral reefs (Barbier *et al.* 2011, Moberg & Folke, 1999, Moberg &Ronnback, 2003). Second, coral formation is an important ecological process that reduces the wave speed, diminishing wave velocity and creating a calm water surface between the reef and the coast. Third, sandy and rocky shores have a similar influence in the water speed but also determine shallow water proper for coral polyps and the accumulation of sand and coral skeletons in the shoreline. White and sandy beaches are the stereotypical image of a Caribbean Island and are highly appreciated. Fourth, nutrient cycling (e.g. carbon and nitrogen cycling) maintains biodiversity which in turn is important for activities such as diving, snorkelling, and boating. Fifth, dry forest and the limestone terrace contribute mostly to landscape amenities like bird watching and hiking, but due to limited available data on these ecosystems (locations and secondary literature) these ecosystems are excluded from the scope of this study.

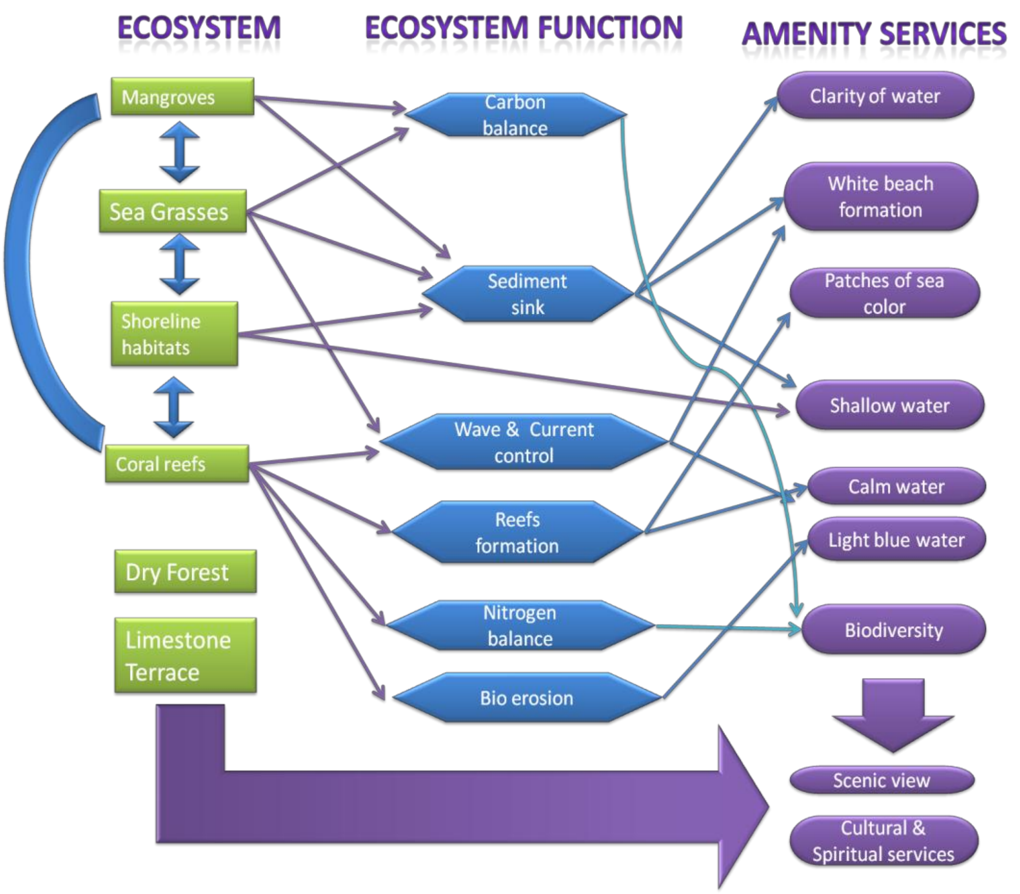

Figure 8.1 Linkage between service “Amenity value” and the ecosystems on Bonaire.

Because of the practical constraints, the scope of this study is limited to the amenity value of Bonaire’s coral reef, which we could include in the analysis by measuring the Euclidean distance between houses and the coast (the coast being a proxy for the coral reef). Initially the analysis also included the mangroves, as measure by the distance over the road, but as no significant results were obtained this ecosystem was dropped.

8.3 Literature

Few studies of the amenity value of coral reef have been executed so far, because these studies are expensive and time consuming and require large and detailed data sets and complex statistical analysis (Pascual and Muradian 2010). Table 8.1gives an overview of the functions identified, methodology applied and results obtained from five studies. These studies were executed on *Hawaii* (Cesar and van Beukering, 2004; Brouwer, *et al.*, 2011), *Guam* (van Beukering, *et al.*, 2007), *Bermuda* (Sarkis, *et al.*, 2010) and the *US Virgin Islands* (van Beukering, *et al.*, 2011). This section will give an overview of the different approaches to measuring reef related amenity value. Coral reef functions, methodology and conclusions from the studies will be discussed.

Table 8.1 Overview of amenity valuation studies on coral reefs

Study area	Functions	Methodology	Results
Hawaii 2004	• Improved views • Better coastal protection	• Expert judgements of real estate agents	Amenity value second biggest factor contributing to TEV Hawaii coral reef → 13% • Annual reef-related property value of the four main Hawaiian islands amounted to US$40 million in 2001 • 1.5% of the sale price of the properties is attributable to the marine ecosystem
Guam 2007	• Beautiful view of shallow coastal waters • Presence of a clean beach and a healthy coral reef	• Hedonic Pricing • 800 houses • GIS map • Variables: structural characteristics • Discount rate 5%, 100 years	• Amenity value second biggest contributing factor to the TEV marine-ecosystems, contributing 8% • Annual amenity value $9.6 million • Six percent real estate value
Bermuda 2010	"People generally prefer living close to reefs"	• Hedonic Pricing • 593 houses • Variables: structural, neighbourhood, accessibility, Bermuda-specific and coral reef characteristics	Amenity value fourth contributing factor to TEV Bermuda coral reef, contributing 1% • Annual amenity value $6.8 million.
Hawaii 2011	Not specified	• Hedonic Pricing • 37,628 houses • Variables: structural, neighbourhood and coral reef characteristics • Coral-related GIS data	• Presence of coral reef has a significant impact on house prices • Cut-off point after 5.5 kilometres
USVI 2011	• Beautiful views of shallow coastal waters • Presence of clean beach and a healthy coral reef is benefit	• Hedonic Pricing • 5,905 houses • GIS map • Variables: structural, neighbourhood, accessibility, environmental and reef quality • "Dynamic method" • Uncertainty analysis • Discount rate 0%, 100 years	• Amenity third largest contributor to TEV USVI coral reefs, contributing 18% • Annual amenity value $37 million • House price increases with more than 100% if the quality changes from average to superior

Why do coral reefs add value to property prices? All studies assume that the presence of coral reefs will lead to improved views, except Brouwer *et al.* (2011) who do not specify the mechanism. Better coastal protection is also cited (Cesar and van Beukering 2004), as well as the presence of a clean beach and a healthy coral reef (van Beukering *et al.*, 2007; van Beukering *et al.*, 2011).

Hedonic pricing is the preferred methodology in these studies, except the study of Hawaii by Cesar and van Beukering (2004), which had to rely on expert judgements of real estate agents. Datasets range from the inclusion of 593 houses (Sarkis, van Beukering and McKenzie, 2010) to 37 thousand (Brouwer *et al.* 2011). While van Beukering *et al.* (2007) included only structural characteristics, sales price and location based on a GIS map other studies were able to refine their measurements by including more variables. The Bermuda study included an extensive list of variables. Structural aspects, as well as neighbourhood characteristics such as average income and such as availability of schools, accessibility (e.g. proximity of important locations), coral reef (vicinity and quality) and Bermuda-specific characteristics such as whether or not a house was located in a flood zone were taken into account. Similar variables were included in the US Virgin Islands study, where in addition to the HP method an uncertainty analysis and special “dynamic method” analysis was applied, which allocates the amenity value on a value map of the coral reef.

All studies demonstrated that coral reefs add amenity value to real estate. Contribution to TEV of the islands ranged from 1% in Bermuda to 18% in the US Virgin Islands. Total annual amenity value ranged from $6.8 million on Bermuda to $37 million on the US Virgin Islands and $40 million on Hawaii. While in general overall contribution of coral reefs to total property value was quite low, the magnitude of combined property value is substantial, and as a result total values were significant. Bermuda’s low values were explained by the fact that the island is very narrow and has widespread high quality reefs. If coral reefs were to degrade it was expected that the amenity contribution would become apparent.

8.4 Methodology

The direct effect that an ecosystem has on market prices of a certain good, in this case houses is commonly estimated with the hedonic pricing (HP) method. A statistical function is estimated relating the dependent “variable property value” to independent variables concerning structural, environmental, neighbourhood and other characteristics which might influence the price (EEA 2010).

No detailed geographic information or extensive list of houses could be obtained. Therefore we constructed a database of private residences in the localities of Sabadeco, Belnem, Antriol, Nikiboko, Lagoen and Hato. Data were obtained from the website: http://www.bonairehomes.com. The following structural characteristics of the property were included: value of the house, year built, size, number of bedrooms, number of bathrooms, lot size, whether it had a garage, and how many stories. No detailed data for location and quality of coral reefs were available so as an alternative the Euclidean distance to coast was taken. We consider this to be a reasonable measurement because the coast near the localities of the houses included in the dataset does not include nice beaches, so it was assumed that beach amenity was not likely to cause collinearity. Following the studies discussed above the mechanism through which the coral reef influences house prices was assumed to be beautiful views (patches of colour) of shallow coastal waters. We also suppose that the possibility of snorkelling and diving close to home is considered to be a benefit.

Furthermore it is possible that living close to the coral reef may be desirable because of positive social status effects. Elevation was included based upon the assumption that the better view these houses enjoy could also distort measurement of the reef related amenity value (Morgan 2010).

The dataset consist of 31 houses corresponding mostly to single family homes and one condominium property. The average price of a house with three bathrooms and three bedrooms is $780,940, while the average distance to the coast is 533 m and to the mangrove 9.4 km and the average elevation is 14 meters. The data shows a considerable variation especially in size, lot size and distance to the coast. Table 8.2 summarizes the variables of the model. All the variables were tested for normality and transformed if deemed necessary; the transformation used can be seen in the value functions below. We couldn't transform the size of the house to a normal function so we discarded this from the analysis. We also discarded stories because the valid number of observations reduced the sample size for the regression.

Table 8.2 Descriptive Statistics

	Valid N	Mean	Minimum	Maximum	Std. Dev.
Value	32	780,939	79,000	2,525,000	633,045
Year Built:	25	2004	1985	2011	8
Size	24	382	85	2980	3
Bedrooms	32	3.5	2	6	1
Bathrooms	32	3.0	1	6	1.4
Lot (m^2)	27	2,044	467	20,451	3,758
Garage	31	0.8	0	2	0.8
Stories	15	1.1	1	2	0.4
Distance to Coast (m)	31	533	0	3770	800
Distance to Mangrove (km)	31	9.4	7.30	12	1.1
Elevation (view)	32	14.4	0	50	19

The model is constructed with the listed variables and a step-wise regression approach was used to select variables statistically significant. The only variable that doesn't appear in linear form is distance to the coast. It is assumed that the price of the house would decrease when located further away from the coastline, hence in the value function distance appears as the inverse form. We determined the hedonic price equation through stepwise regression analysis. Our final calculation includes 21 cases from the original 31 due to the missing values. This results in the following value function:

$$Value = ß0+ß1 log(LotSize) + ß2NBEDROOM + ß3NBATHROOM + ß4/LN(Distance)+ ß5elevation+ ß6Year$$

$$Value =ß0+ß1 log(LotSize) + ß2NBEDROOM + ß3NBATHROOM + ß4/Distance\_Mangrove+ ß5elevation+ ß6Year$$

8.5 Results

Table 8.3 and Table 8.4 summarize the result of the regression, showing the both the statistically significant and non-significant variables. The price in our “distance to the coast model”, table 3, is explained substantially by the independent variable variables (R^2=55%, p<.01), being the number of Bathrooms the only variable that was significant in our model (p<.05), contributing to 82% of the price. We obtained similar results for the mangrove model (Table 3) with the similar explanatory power of the independent variables but not statistically significant (R^2=54%, p<0.10). Our results face one of the major limitations of the hedonic pricing methods that is a lack of a comprehensive database. The reduced and incomplete database would provide reduced amount of quality data for satisfying the assumptions of the statistical analysis. We are not able to apply the hedonic function of other studies, for example Guam’s coral reef amenity value (van Beukering *et al.* 2006). Due to an absence of information about the number of houses available and its distances from the coast, we cannot extrapolate a Total amenity value of the coral reefs in Bonaire.

Table 8.3 Regression model summary (with environmental variable distance to the coast)

	Beta	Std. Err. - of Beta	B	Std. Err. - of B	t(13)	p-level
Intercept			29944647	35851777	0.835235	0.418672
Year Built:	-0.174502	0.207866	-14749	17569	-0.839493	0.416364
Bedrooms	-0.234349	0.288525	-173842	214030	-0.812232	0.431281
Bathrooms	0.825631	0.295474	433223	155040	2.794262	0.015196*
Lot	-0.086184	0.233159	-170412	461031	-0.369634	0.717607
Garage	0.396959	0.195921	344817	170186	2.026115	0.063781
Distance coast	-0.127450	0.212505	-315782	526524	-0.599749	0.558983
Elevation (view)	0.049986	0.199647	1787	7136	0.250371	0.806214

N=21, Adjusted R2= .55 F(7,13)=4.5692 * Significant variables at 5%

Table 8.4 Regression model summary (with environmental variable distance to the mangrove)

	Beta	Std. Err. - of Beta	B	Std. Err. - of B	t(13)	p-level
Intercept			22102176	33183480	0.666060	0.517019
Year Built:	-0.127485	0.190772	-10775	16124	-0.668261	0.515657
Bedrooms	-0.135227	0.247828	-100312	183841	-0.545646	0.594549
Bathrooms	0.757233	0.277348	397333	145530	2.730258	0.017173*
Lot	-0.101500	0.233988	-200699	462670	-0.433784	0.671557
Garage	0.468068	0.213097	406585	185106	2.196505	0.046797*
Distance to Mangrove	-0.054505	0.204765	-30669	115219	-0.266181	0.794275
Elevation (view)	0.043957	0.201939	1571	7218	0.217677	0.831060

N=21, Adjusted R2= .55 F(7,13)=4.4302, * Significant variables at 5%.

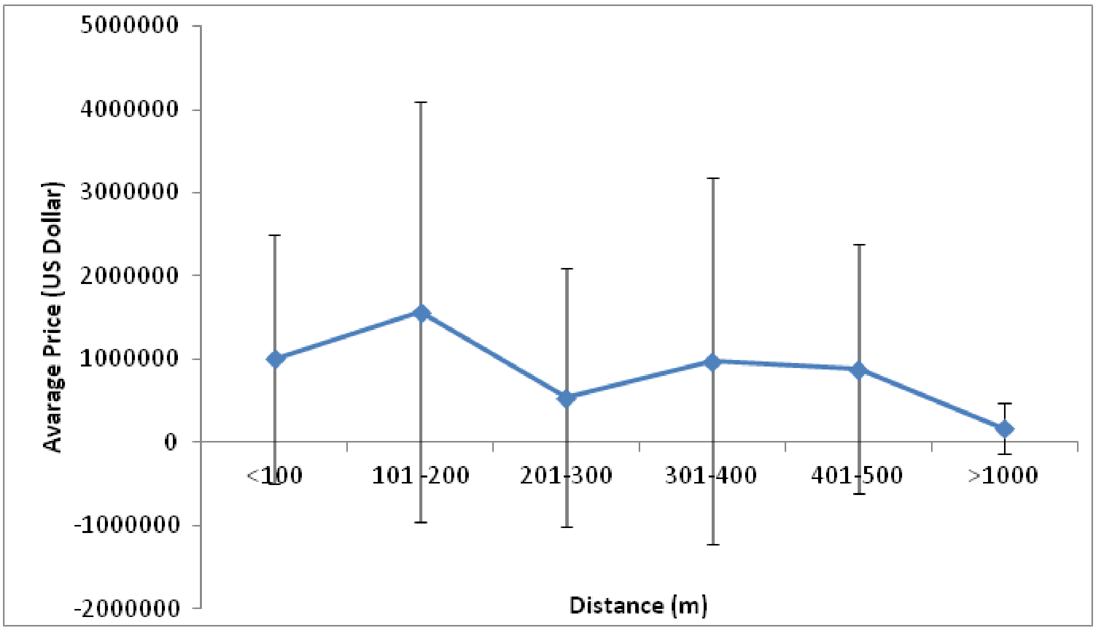

Figure 8.2 Average price of the household in function of distance categories. Bars represent standard deviation

The hypothesis to be tested by this study is as follows: "*property values are not only determined by conventional house and neighbourhood characteristics, but also affected by the presence and quality of Bonaire's ecosystem".* From the statistical analysis no strong significant impact of environmental variables onto the house prices has been detected and thus the hypothesis is rejected. This lack of evidence limits the possibility to calculate the amenity value.

The poor performance of the statistical model can be caused for various reasons. First, the lack of significance of the variables could be attributed to non linear relationship between the variables. For example, the relationship between houses' prices and distance from the beach in Bermuda showed a quadratic function where the house prices first increased when further away from the beach and from about 1.1 km house prices decreased (Sarkis *et al.*, 2010). Second, there is no clear distinction between coral-reef related variable (distance to coast) and ocean related variable (elevation; ocean view), there is a high correlation between the coral reef ecosystem and the marine environment in such a small island like Bonaire as also was the case in Bermuda. Third, the amenity value is further underestimated within this study because of the fact that the contribution hotels, offices and shops get from Bonaire's coral reef amenity value is beyond the scope of this study and thus not included. Fourth, the surplus value of houses in the vicinity of healthy coral reef systems could not be measured within this study since the data on the number of residential homes and their respective locations were not available, to make an estimation would be futile and would surely be far off the real amenity value. Finally, the dataset for this study is greatly limited in number of explanatory variables as well as number of cases (N).

8.6 Discussion and recommendation

Bonaire faces many challenges to the management of its marine environment; over-fishing, nutrient enrichment, land-use change, poaching, heavy recreational use, sedimentation, illegal sand mining, artificial beach creation, invasive species, terrestrial run-off (IUCN, 2011). These threats could be further exacerbated in the future by climate-change ramifications such as coral bleaching. Although this study failed in estimating the amenity value for Bonaire, from the literature review and from presentations by representatives in Bonaire it is clear that coral reefs is of much importance to the island.

It was suggested by a former government employee of the island that there is a limitation to valuing the contribution of only one of the ecosystems (coral reef) when all of Bonaire's nature combined is what makes the island unique. While the hedonic pricing method detects relationships when there is sufficient variability in the data, the relationship that was suggested by the government employee of Bonaire suggests one of little variability; meaning everyone enjoys the fact that Bonaire is a "nature paradise". A good dataset would be needed to make this relationship manifest itself.

Amenity value may not be present in large sums of money until the ecosystem has been degraded. The low values that were found on Bermuda were attributed to the fact that the island was very narrow and had widespread healthy coral reefs, it was expected that the amenity contribution would become apparent if coral reefs were to degrade (Sarkis at al., 2010). This might be the case in Bonaire as well and finding an amenity value through hedonic pricing method alone would not be sufficient for representing amenity value, in this case a corresponding survey would bring more clarity.

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9 Cultural value

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9.1 Introduction

The island of Bonaire has a precious though threatened nature and its culture is indistinguishable from nature. Agriculture has always been a very important practice on Bonaire. After the abolition of slavery, Bonairean continued with agriculture, but in a way that was more in harmony with nature (also more sustainable). However, since the development of industrial times, less Bonairean practise agriculture, and less people are working in the nature.

The objective of this study is to estimate the value of the cultural ecosystem services of the island of Bonaire. This is a challenging objective as cultural ecosystem services are among the most difficult services to measure and quantify and consequently value. Therefore, the ambition will be to make an attempt to value several of those cultural ecosystem services without making an attempt to give a complete overview of all cultural ecosystem services.

The structure of this Chapter is as follows. Section 9.2 starts by defining cultural ecosystem services, and selecting the cultural services that are within the scope of the study. Section 9.3 describes the various valuation methods available for valuing cultural ecosystem service. Section 9.4 will demonstrate the actual valuation process and Section 9.5 will conclude this study with recommendations to improve the estimated values further. Note that the study will involve mainly literature study, interviews and value calculations to answer the research question.

9.2 Background and literature

MEA and cultural ecosystem services

Cultural services are one of the four categories of ecosystem services as defined in the Millennium Ecosystem Assessment (MEA). They are the non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience, including, e.g., knowledge systems, social relations, and aesthetic values (MEA, 2005). The MEA proposes a list of ten cultural ecosystem services:

1. Spiritual and religious values
2. Aesthetic values
3. Tourism/recreational
4. Cultural diversity
5. Knowledge systems
6. Educational values
7. Inspiration
8. Social relations
9. Sense of place
10. Cultural heritage values

All those services apply to the context of Bonaire, but because tourism is covered by another of the parallel studies (see introduction), we will exclude tourism from our scope.

Cultural ecosystem services on Bonaire

In 2010, the Bonaire Culture Policy plan has been formulated (Beleidsnota cultuur Bonaire, 2010). Consultation of the stakeholders on the island, including the local inhabitants, was conducted prior to the formulating of the plan by way of interviews and conducted surveys. This plan shows more insight on what the Bonaire people themselves consider cultural values of high importance.

In general, the plan underlines the fact that its aim is 'the strengthening of the natural synergy between culture and nature, of which culture must be seen as the celebration of nature'. Because, as it is stated: 'Without nature Bonaire has no culture'. This broad statement calls for more specific definitions of the cultural ecosystem services, and has resulted in the formulation of a few policy goals. The first goal, the 'protection and promotion of cultural heritage', has been given the highest priority, because of the high importance it has been given by the stakeholders and the local community. This policy goal consists of a few spearheads which should be protected and promoted:

- The 'Marshe di Rincon' (*Marketplace Rincon on Bonaire)* with more folklore, norms and values, traditions from the past, use of herbs, kunukus (*typical Bonaire farms)*, oral history, patriotism, folklore, religion.
- The transfer and conservation of the typical Bonaire fishery, agriculture and navigation culture, since Bonaire has a strong relationship with the sea.
- Conservation and promotion of Papiamentu.
- Writing down and stimulating culinary traditions of Bonaire.
- Conservation of nature of Bonaire.
- Protection and maintenance of the monuments of Bonaire.

In order to refine the scope of this study further, we conducted an interview on the 7th of October 2011 with the chairwoman of the project team of the Cultural Policy Plan, Mrs. Liliane de Geus. She notices a tendency towards an increasing awareness for protecting the norms and values of the island as being of high cultural importance for the Bonaire people. Those tendencies are often shown by way of protecting: the local language *Papiamentu,* the kunukus, and the cultural dances.

The scope of this study will contain the valuation of four cultural values of ecosystems on Bonaire:

1. **Recreational activities on the beaches**. Activities like barbequing, swimming and relaxing on the beach are important activities for the Bonaire people, according to a survey conducted in 2011 (Lacle, 2011).
2. **Subsistence and recreational fishing.** Bonaire people have a strong relationship with the sea, being on an island. Both subsistence and recreational fishing are activities practiced at a large scale.
3. **Kunukus.** These little farms can be found everywhere on the island. The *kunukeros* (farmers) hold cattle and grow all kinds of vegetables, of which a lot of indigenous species. For a lot of Bonaireans kunukus are a way of expressing their culture since most kunukus are exploited on a recreational basis (Beleidsnota 2010). Also, the kunukeros play a dominant role in the celebration of 'Oogstfeest'

(Harvest Day). This day is held in March or April, and consists of a party where family and friends come together to harvest 'sorghu,'(a local weed). The kunukeros deliver the drinks and the food for this Harvest day (Beleidsnota 2010).

4. **Cultural landscape.** The cultural landscape consists of the aesthetical, identity and sense of place values that make a landscape the place it is (Schaich, 2011). The cultural landscape features of Bonaire are all the features that characterize Bonaire, like the kunukus, the beach etc.

These four cultural ecosystem services will be valued in this study and explained into more detail in chapter 3.

Threats to cultural ecosystem services in Bonaire

One of the main reasons to value those ecosystem services is that they are being threatened, and there is a need to create awareness on what services can be lost if no actions are taken. The main threats to the cultural ecosystem services in scope of this study are shown in Table 9.1below.

Table 9.1 Threats to cultural ecosystem services in Bonaire

Affected service	Threatened by:
Recreational activities on beaches	• Coastal development and diminishing public beach access • Increase in cruise tourism visitor spending time on the beach (crowdedness & impact on environment) • Decrease of water quality (mainly by industrial practices) • Risks of marine oil pollution accidents • Risks of pollution from international marine shipping (including supposedly nuclear waste trans-shipment) • Waste from yachts and cruise liners
Subsistence and recreational fishing	• Overfishing (More local fisheries and large foreign commercial fishing vessels outside EEZ) • Destruction of coral reefs (leading to decreasing fish populations) • Invasive species (such as the Lionfish) • Risks of marine oil pollution accidents • Risks of pollution from international marine shipping (including supposedly nuclear waste trans-shipment)
Kunukus	• Deforestation / loss of vegetation by free roaming goats and donkeys (causing soil not retain rainwater and thereby making it too salty to exploit) • Increase in tourism, thereby finding a better paid job somewhere else (change in culture) • Extraction of diabaas (natural resource for building houses/ construction) instead of agriculture and live stock on same piece of land) • Loss of social cohesion
Cultural dances celebrating nature	• Younger generation not willing to keep cultural traditions alive • Lack of transmission from older generation (as they don't always adhere to the new rules)
Cultural landscapes	• No monetary value for landscape and therefore unwise decision regarding development takes place (construction/ coastal development) • Political favours • Loss of kunukus (see above) • Increase in population, necessity of developing land • Extraction of diabaas (deep holes in surrounding landscape, use of caterpillars)

In 2003, Chiesura found out in a study made on the Dutch Caribbean islands that "a key threat is being brought about largely by the tourism industry itself, despite its reliance on beaches to attract visitors. Many poorly planned developments are simply too close to the coastline and thus to the sea. These coastal properties often lack adequate waste-disposal facilities, which lead to contamination with sewage and other effluents, causing a health hazard and badly diminishing the aesthetic value of beaches. Failure to set buildings back 50 m or more from the shore also exposes them to storms and damages dunes which are part of the dynamic system stabilizing beaches" (Chiesura, 2003). This still applies greatly today to most of the cultural ecosystem services in scope of this study.

Another threat to be highlighted is the influence of foreign (Dutch and Latin American) culture and attitudes that changes local traditional values (Beleidsnota Cultuur, 2010). The constitutional change brought with it a huge influence of Dutch efficiency and effectiveness changes way of doing things which lead to less interest in keeping traditional values intact.

9.3 Methodology and results

A framework has been established to visualize the relationships between the key ecosystems available in Bonaire, the ecosystem services selected for the scope of this study based on the criteria defined in paragraph 2-2, the valuation methods identified as best suitable and the value of the cultural ecosystem services of Bonaire. It is depicted in the figure 3 below.

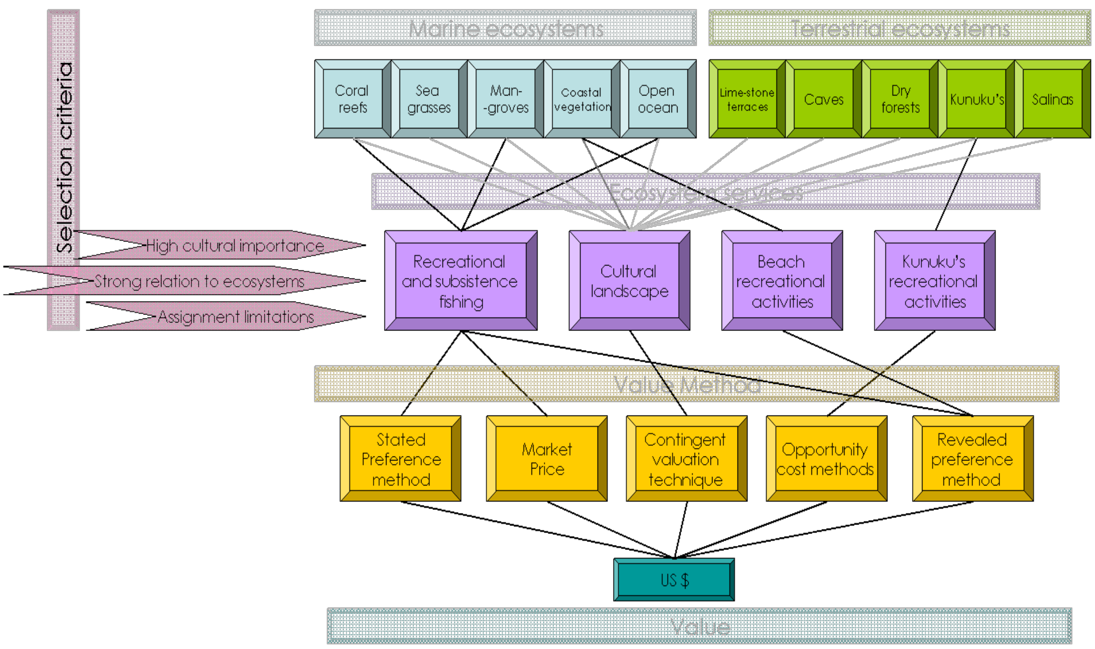

Figure 9.1 Proposed framework for cultural ecosystem services valuation in Bonaire

The cultural services provided by nature are an integral part of human wellbeing. However, because the state of "feeling good" is not traded in the market place, it is difficult to put a price tag on cultural ecosystem services. Moreover, cultural services and other types of services are jointly provided by one ecosystem, which makes it hard to disentangle the effect of cultural services from the rest. In this study, each service will be valued through individually targeted valuation techniques.

Kunukus

Figure 9.2 shows a few examples of Kunukus on Bonaire. Kunukus are mainly an addition to the food supply, used as a hobby and used out of tradition by the kunukeros (Beleidsnota, 2010). Also the kunukus are the foundation for the harvest day, a special day on which the harvest is celebrated. The food supply should not be recognized as a cultural value, since it is an addition to the income of the farmers. However, the use for recreational purposes can be considered as a cultural service.

Figure 9.2 Examples of kunuku houses in Bonaire.

The survey done by Lacle (2011) indicates that these cultural values are very relevant on Bonaire. None of the 387 respondents indicate that they have agriculture as a profession. Since most of the islands rural landscape is characterized by kunukus, one can conclude that the recreational importance of the kunukus is, therefore, very high. From the inland households, 47% owns a kunuku. Also, of the 133 respondents that specifically indicated a location for their barbecues and picnics, 36 indicated the kunuku as their favourite location. The beach was another favourite location.

The difficulty in assessing the value of the cultural ES of the kunukus is twofold. First of all, the cultural and subsistence value should be separated. Secondly, the value of the kunuku should be determined. A possible method would be to estimate the time that people are working in the kunukus. This time is valuable by estimating what leisure time is worth in Bonaire through opportunity cost methods. By estimating the price of the produced goods of the kunukus, it is then possible to determine the additional recreational and identity values of the kunukus.

Problematic in estimating the value is that there is no data on time spent in the kunukus and no data on the production that comes from the kunukus. Transferring other studies about the values of subsistence farming in other countries are also not appropriate, since the value of the kunukus is much more of a recreational nature then is normally the case.

Fishing

Also fishing is done for subsistence, income, traditional and recreational reasons (see Figure 9.3). In Lacle's household survey (2011), many fishermen answer positively to the question whether they enjoy fishing (75%). Only 5% of the respondents sell their catch, but they do go out fishing most often and catch most fish per trip. About 19% gives away part of their catch. When asking about the traditional value 12% of the fishermen replied that they fished because of tradition. A large 26% said that fishing strengthens the social bonds on the island.

Figure 9.3 Examples of fishing recreational activities in Bonaire.

This indicates that the cultural importance of fishing is high. Most fishermen don't fish because of monetary gains, but because of other reasons that can be largely labelled as cultural. It will be impossible with the available data to disentangle the cultural and subsistence values, since many of the fishermen value both the food source and the cultural services provided by fishing. However, being a subsistence fisherman is also influenced by intergenerational and traditional motives.

There are some other studies that tried to capture the cultural value of fishing. Van Beukering *et al.* (2007) use a similar questionnaire in their survey to identify cultural importance of fishing on Guam. The findings on the importance of different cultural aspects are very similar to the ones on Bonaire. By designing a choice experiment the additional cultural value of fishing is estimated. Two situations are described, one in which only a fishmeal is available for oneself and a second and third in which the sharing of fish is also possible and the amount of specific cultural fish are more abundant. The authors calculate that the added value of cultural fishing is about $43 per year, whereas the value of own fish meals is roughly $90 dollars per year. This is quite a substantial rise.

Another study by van Beukering *et al.* (2006) on the Mariana Islands shows again comparable results in the composition of reasons to go fishing. An interesting result in this study is that the costs to go fishing (boat hire, fuel, renting fishing gear etc.) almost always exceed the sales income for every income category of fishermen except for the highest category, the professional fishermen. This indicates that the only reason to sell fish is to cover some of the costs made to go fishing. Since the Guam and Mariana Islands are inhabited by communities with different culture than the island of Bonaire is, transferring these values would be unreliable.

Cultural Landscape

When valuing the cultural landscape of Bonaire (see Figure 9.4), we mostly consider the aesthetical, identity and sense of place values that make Bonaire the island that it is. Without its large areas of kunukus, its mangroves, dry forests and its coral reefs the island would not be valued the same for non-use purposes. To estimate the cultural values of the landscape of Bonaire, it is possible to use a contingent valuation technique. By using questionnaires it is possible to estimate the willingness to pay for maintaining the quality of the cultural landscape.

Another approach to valuating the cultural value of the landscape would be to compile the cultural map indicated by Schaich (2011) by asking locals to identify on a map sites answering the following questions:

- Are there religious or places sacred to you in the landscape, and where? (spiritual/religious services)
- Where are the most beautiful places here? (aesthetic values)
- Where do you go in your spare time? Are there, for instance, any meeting places important to you or do you go to the surroundings? (recreational services)

Figure 9.4 Examples of cultural landscape in Bonaire

More questions can be added to this list, and more sites could be identified by reviewing historical documents, or conducting interviews with community elders and public agencies. A narrower means of valuating the cultural landscape is suggested by Boyd & Waigner (2003), who suggests that the number of rare fauna and flora on the island would be a good indicator for the cultural value of the island. A similar indicator would be the number of visits/visitors to natural and cultural parks, as well as the value of entrance fees, donations and voluntary work.

Beach recreation

The household survey shows that the particular recreational service on the beach is of a large importance to the Bonairean people. Especially barbecuing, relaxing and swimming are very important activities. Relaxing, wading and swimming are performed more than 6 times per year by between 65 and 75% of the respondents. 57% of the respondents barbecue more than 6 times per year on the beach.

Since we also are in possession of a choice experiment where the beach accessibility is traded off with monetary indicators, it is possible to estimate the value of beach recreation through a stated preference method. According to the study by Lacle (2011) the average household willingness to pay for an increase of 20% (taken from a decrease of 20% predicted for the current development of the island to no change) in beach access is about $9 per household per month.

Although the willingness to pay for beach accessibility is probably non linear, due to a decrease in marginal utility as the accessibility increases it will be hard to estimate the total value of beach recreation. On the other hand, it is very unlikely that the beaches will not be accessible anymore at all, so changes in accessibility will be a very useful tool for policymakers to determine their plans for beach development.

Following from the household survey, the average household in Bonaire consists of 2.95 people, the total population is 15,000 implying 5,085 households. This means that the total value of not decreasing the accessibility by 20% is $45, 000 per month and $550,000 per year.

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10 The ecological footprint of cruise ships in Bonaire

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10.1 Introduction

Marine Positive developed a model in cooperation with the Polytechnic University of Marche, Italy. The model is called Acquatrail and is an offsetting system. The Acquatrail is the aquatic equivalent of the carbon footprint in the sense that it takes water pollutants into consideration, i.e. gaseous, liquids and solids that damage aquatic environments. By contributing alongside carbon and water footprints it provides a holistic picture of anthropogenic impacts on marine environments[10]. The data required for the input of the Acquatrail calculations was provided by Imares of the Wageningen University.

The goal of this study is to calculate the ecological footprint of cruise ships on coastal waters in Bonaire. The Acquatrail model will be applied accounting for multiple stressors on the affected ecosystems. The Chapter will first present the emission data in Section 10.2 after which these effects are monetised and presented in the results Section 10.3.

10.2 Total emissions in Bonaire waters

Based on international regulations, no bilge water, black water and grey water is discharged in Bonaire's waters. No information on oil and grease could be found during execution of this study. Below follows a set of summaries that provide antifouling emissions and the related concentrations in the environment (see Table 10.1, Table 10.2 and Table 10.3). Specification per ship and visit, and division to compartment (harbour versus shipping lane) are provided in the report.

A thorough search of the EPA database was conducted in order to find the No Effect Concentrations (NOEC) of antifouling compounds on corals. The lowest values found are presented in the report. These values are much higher (up to factor 100.000) than the calculated concentrations in the environment. It is assumed that such low concentrations impose no risks for corals.

Table 10.1 Antifouling emissions in season 2011-2012

	Copper	TBT	Diuron	Irgarol
Total Emission (grams)	11,512	1,713	464	464

[10] For more information see: www.marinepositive.com

Table 10.2 Antifouling concentrations in the environment after 10 years, based on emissions in season 2011-2012

Concentration (µg/L)	Copper	TBT	Diuron	Irgarol
Maximum	0.00032	0.00005	0.00001	0.00001
Average	0.00024	0.00004	0.00001	0.00001
Median	0.00004	0.00001	0.00000	0.00000

Table 10.3 Gross Gaseous emissions

	Total emissions 2011-2012
NO_x (tonnes)	0.3122
CO_2 (tonnes)	157.6108
SO_2 (tonnes)	0.046

IMARES estimated the emissions and environmental concentrations, based on general calculations, and modelling. These values are in turn submitted to Marine Positive ltd. Marine Positive used this data to calculate the monetary equivalent of the emissions on Bonaire. No additional field measurements are done in this study.

Some basic assumptions are made:

- Selection of cruise ships: ships visiting Bonaire in the season 2011-2012 are taken into account (Table 10.4).
- The “Freewinds” are not taken into account due to lack of information on actual port calls.
- Region: The emissions are estimated for the “Bonaire region”. This region is defined by:
    - Shipping lane: based on the fact that the ships enter Bonaire from the territorial Water line (12 nm). The emissions in the shipping lane are estimated on a 2* 12 nm length, and estimated duration based on their individual speed.
    - Harbour: it is assumed that the ship moors around 10 AM, and departs around 17 PM. Total duration in the port per visit is 7 hours.
- Tug boats assisting cruise ships are not included.

Table 10.4 Cruise ships that visit Bonaire in season 2011-2012

Vessel	Cruise line	Passengers	Visit Bonaire
AidaLuna	AIDA Cruises	2050	7
Azura	P&O Cruises	3080	3
Breamar	Fred Olsen	927	2
Caribbean Princess	Princess Cruises	3100	12
Emerald Princess	Princess Cruises	3100	10
Grandeur of the Seas	Celebrity/RCCL	2446	18
Maasdam	HAL	1258	4
Noordam	HAL	1918	6
Ventura	P&O Cruises	1950	3

10.3 Emissions and resuspension of sediment of cruise ships

In upcoming sections, the emissions from antifouling paints and gaseous emissions are further described and specified for the Bonaire region. Emissions from black water, grey water, bilge water, ballast water and oil and grease were not further specified in this study. Cruise ship emissions are categorised in:

- Black water
- Grey water
- Ballast water
- Bilge water
- Antifouling
- Oil and grease
- Gaseous emissions

Black water & Grey water

"Black water," is the sewage from vessels consists of human body waste and the waste from toilets and other receptacles intended to receive or retain body waste (including medical waste). Grey water is wastewater generated from domestic activities such as laundry, dishwashing, and bathing

On Bonaire, black water and grey water are not disposed on land (pers comment van Slobbe). Black and grey water from the cruise lines visiting Bonaire[11] are processed through a Marine Sanitation Device (MSD), certified in accordance with US or international regulations, prior to discharge. Discharge takes place only when the ship is at minimum distance of 12 nautical miles from land.

We assume that the visiting vessels act according to this international agreement, and that no black and grey water is disposed in the coastal waters of Bonaire. Wastewater is then no aspect of the cruise ship footprint for Bonaire.

Bilge water

Large vessels such as cruise ships have several additional waste streams that contain sludge, waste oil, and oily water mixtures, including fuel oil sludge, lubricating waste oil, and cylinder oil, that find their way to the bilge. The bilge water can be managed in one of two ways (Sweeting *et al.* 2003):

1. Retained on board in a holding tank and discharged later to a reception facility on shore; or
2. Treated on board with an Oily Water Separator (OWS).

The treated bilge water can be discharged overboard in accordance with applicable standards and regulations while the petroleum products extracted by the OWS (i.e., oily waste) are retained in a dedicated holding tank on board (and later be incinerated and/or off-loaded in port).

The international standard established by MARPOL (Annex I), and implemented into United States law by APPS, states that machinery space waste including bilge water may be discharged overboard if it contains a concentration of 15 ppm oil or less. This only applies to ships beyond the 12 nm limit, provided that the ship is underway. We assume that the vessels act according to the international agreements, and that no

[11] This statement holds for all cruiselines in Table 10.1, but remains uncertain for Fred Olsen and Hansa kreuzfahrten lines.

bilge water is discharged in the coastal waters of Bonaire. Thus, bilge water is not an aspect of the cruise ship footprint for Bonaire.

Ballast water

Cruise ships use ballast water to stabilize the vessel during transport. Ballast water is often taken on in the coastal waters in one region after ships discharge wastewater or unload cargo, and discharged at the next port of call. Ballast water discharge typically contains a variety of biological materials, including plants, animals, viruses, and bacteria. These materials often include non-native, nuisance, exotic species that can cause extensive ecological and economic damage to aquatic ecosystems. Ballast water discharges are believed to be one of the leading sources of invasive species. Emissions ballast water and invasive species are not included in this assessment as ballast water is assumed not to be discharged in the coastal zone.

Oil and grease

Oil and grease are used on e.g. propeller shaft, and can leak into the water during normal use. In extreme cases when propeller shafts break, these compounds will spill into the environment. No specifications on type of oil and grease, and the spillage, and uses could be retrieved during this quick scan study.

Antifouling

Anti-fouling paint is a type of coating applied to the hull of a ship in order to slow the growth of organisms that attach to the hull and can affect a vessel's performance and durability. Antifouling paints contain toxic substances that hamper growth of barnacles, algae, and other marine organisms. Usual substances are copper, organotin compounds, or other biocides. For each ship, the emissions from antifouling paints are estimated. Only the active ingredient is taken into account. No emissions from auxiliary substances were calculated, as information on these substances could not be retrieved during this study.

Sedimentation

Large cruise ships can resuspend amounts of sediment that drift onto nearby reefs. The research from Jones (2011) states that based on existing literature, the intensity, duration and frequency of sediment exposure were considered unlikely to result in discernible physiological impacts on adult corals in the short term. However it could not discount long-term effects on juvenile coral survival and settlement success. Corals beside the shipping channel are likely to be exposed for several hours to suspensions of very fine sediments. Most studied corals have been found to move sediment influxes of up to 50 mg DW sediment in cm^2 with comparative ease and up to 200 mg DW sediment cm^2 within a few days. However this could result in a diminished ability to generate new recruitment. Over many years there could be a gradual loss of the existing coral community and replacement by more sediment tolerant species or communities. Further and more applied research should be done on Bonaire on this topic. One of the possibilities given by Jones is that lower speed of the cruise ship generates lower sediment suspension (Jones, 2011).

10.4 Results

As shown in Table 10.5, the total costs that cruise ships entering the Bonaire harbour impose on the environment in 2011 is estimated at US$100,000. For these calculations of costs as represented in gaseous emissions, antifouling emissions, liquid and solid waste emissions are included using various sources to estimate the monetary value of the environmental impact.

Table 10.5 Overview of elements, quantities and costs of the environmental impact of cruise ships entering Bonaire harbour

Environmental impact	Quantity	Value	Total in Euro	Total in US$
Gaseous Emissions (tonnes)		**Euro/tonne**		
CO_2	5496	8	43,968	57,376
NOX	44.6	32	1,427	1,862
SO_2	109	64	6,982	9,112
Antifouling Emissions (kg)		**Euro/kg**		
TBT	1.71	7,417	12,683	16,551
Copper	11.51	552	6,354	8,291
Diuron	0.46	4,108	1,890	2,466
Irgarol	0.46	1,369	630	822
Liquid (wastewater) Emissions (m^3)		**Euro/m^3**		
Black water	13,467	0.05	673	879
Grey water	67,292	0.1	6,729	8,781
Solid Waste		**Euro/tonne**		
Solid waste	337	4	1,348	1,759
Total environmental costs			82,684	107,899

Note: Conversion rate from euro to USD is 1,288 on 13 September 2012)

The gaseous emissions CO_2, NO_x and SO_2 were converted using US-EPA (2008) as a source. Direct Emissions from stationary combustion sources were based on EPA430-K-08-003 and estimated using an inventory of data from GaBi 4.3 software. The monetary conversion factors take into consideration the vulnerability of tropical aquatic ecosystems and are as follows: 8 Euro/ton CO_2, 32 Euro/ton NO_x and 64 Euro/tonSO_2. These monetary values are based on EU trading costs (minimal estimate). NO_x and SO_2 are based on vulnerability due to eutrophication potential.

The antifouling emissions are based on potential ecotoxicological effect and eco-system values. For antifouling (TBT, Copper, Diurno, Irgarol) we used values of each category on the NEOC basis, estimating the overall surface in contact with water and the depreciation of one hectare of ecosystem at ca. 4,500 Euro/ha (Costanza *et al.* 1997, Nature).

Liquid wastewater emissions and solid waste projections of on board waste are calculated as a negative ecosystem externality (external costs) due to human sewage on the ship. Estimates for black and grey waters taking into account a per-person average of black water equal to 0.02 m^3/d and of grey water equal to a 0.1 m^3/d. The quantity of water was multiplied by an empirical cost equal to 20-40% of the taxes payable to have water treatment based on Italian costs. For solid waste Marine Positive used an average per-person of 0.5 kg/d. The total was multiplied by 5% of the taxes payable for refuse disposal based on Italy (pers comment Marine Positive).

10.5 References

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Annex 10.A Technical details of emissions calculations

MAPMEC

The Marine Antifouling Model to Predict Environmental Concentrations (MAMPEC 3.0.1 beta, Deltares|Delft hydraulics, IVM) was used in the present study to calculate environmental concentrations of components in antifouling paint. MAMPEC has three distinct input modules: 'environment'; 'compound' and 'emission'. In the 'environment' module, environmental characteristics are specified. In the present study, two environmental types are distinguished: 'open harbour' and 'shipping lane'. Parameterisations of these modules are described in the sections below, as are the parameterisation of the other two modules. The compound module encompasses the chemical-physical properties of the toxicants and the 'emission' module, which portrays the rate of emission of these toxicants.

Parameterising open harbour characteristics for MAMPEC calculations

MAMPEC uses rectangular shaped harbours for its calculations (cut-out illustration in Figure 10.1). However, the actual harbour compartment in Cuxhaven does not have an exact rectangular shape (Figure 10.1). The following text describes how (the dimensions of) the environmental compartment is parameterised. The width of the harbour compartment (y1) (Figure 10.1) was set to 100 m. The length of the harbour compartment (x2) was set on 300m. The length of the coastal stretch included in the calculation (x1) is set to 450 m, in part due to model restrictions. These and other needed parameter settings are summarised in Table 10.6.

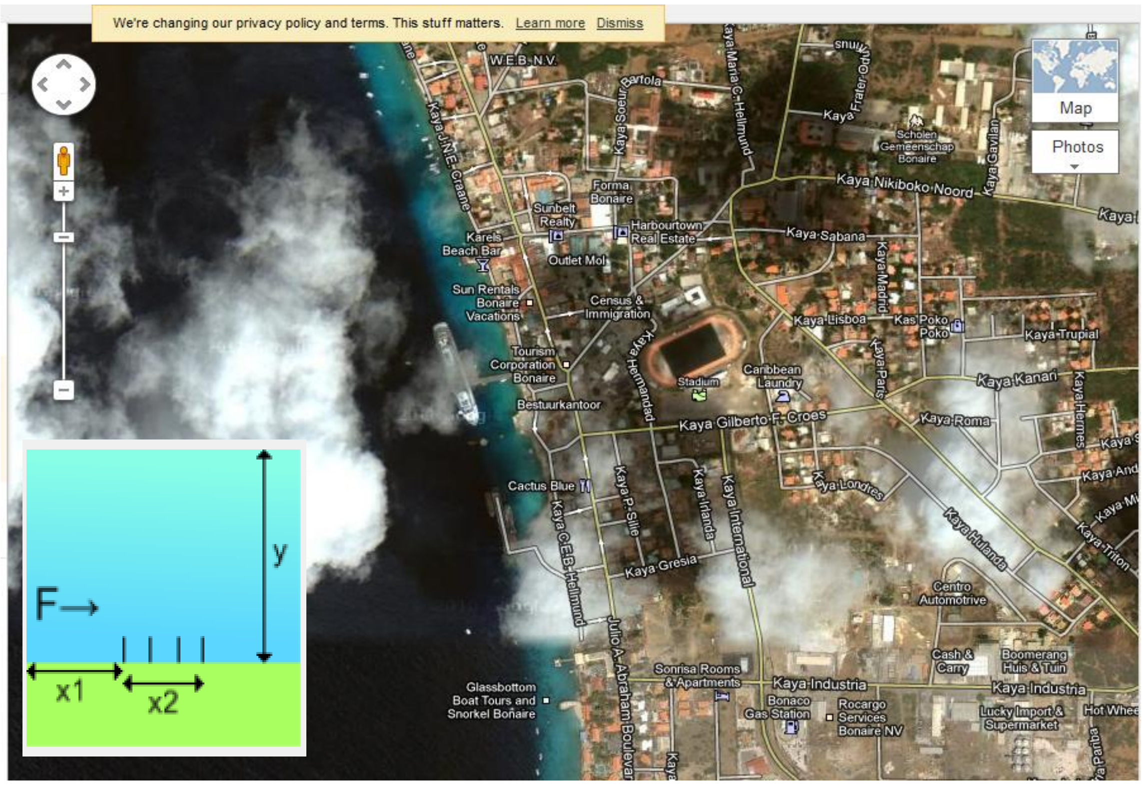

Figure 10.1 Top: satellite view of the harbour and berth at Kralendijk (source: Google Earth); bottom: schematic representation of relevant harbour compartment. Distances are estimated with ruler tool in Google Earth

Table 10.6 Parameter settings for environmental compartment in MAMPEC

Parameter name	Parameter description	Parameter value	unit
x1	Length coastal stretch included in calculations	0.450	km
x2	Length harbour compartment	0.300	km
	Depth harbour compartment	2.5	m
F	Flow velocity	0.0093	m/s
tp	Tidal period	10	h
Cs	Silt concentration	?	mg/L
POC	Particular organic carbon concentration	?	mg OC/L
DOC	Dissolved organic carbon concentration	0.085	mg/L
Chl	Chlorophyll concentration	0.13	µg/L
S	Salinity	36	s.e.
T	Temperature	28	°C
L	Latitude	-68	° NH
pH	pH level of water	8	-

Parameterising shipping lane characteristics for MAMPEC calculations

For the shipping lane MAMPEC also requires specified dimensions (Figure 3)). For the length of the shipping lane (x), the length of the average route from the harbour to the territorial water line is taken (2* 12 nm= 24 nm= 38.6 km). For the width of the shipping lane (y), the default value of MAMPEC is used (10 km). An estimate for the depth of the shipping lane is difficult. The depths vary from -250m to -70, caused by various drop offs and submarine terraces. In the end, an average water depth of 70 m is used for the shipping lane. Other required characteristics are identical to those listed in Figure 10.2.

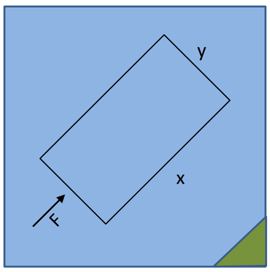

Figure 10.2 Shipping lane dimensions as required by MAMPEC

Parameterising emission characteristics for MAMPEC calculations.

Before emissions could be parameterised, first all relevant chemical components need to be identified. International Maritime Organisation's Antifouling System Convention entered into in 2008, and bans the use of Tributyltin (TBT) based antifouling paints globally. However, if the ships are painted before 2008, TBT can still be the current coating on the ship's hull. AIDA Cruises, P&O Cruises, and Princess Cruises have applied silicon based anti-fouling marine hull coating systems to some of their vessels. This paint technology reduces the ship's drag due to the non-sticky characteristics, and reducing fuel consumption and air emissions. Such coatings are also biocide-free, making them more environmentally acceptable than biocide-releasing technologies (Carnival report 2007). Hulskotte *et al.* (2007) state that in principle silicone antifouling paints contain no additional compounds paints, as the mode of action is their non-sticky characteristic. Table 10.7 provides an overview of used antifouling paints per ship. Antifouling characteristics per ship are retrieved from the National Pollutant Discharge Elimination System (NPDES)[12]. Based on the antifouling type, the main anti-fouling components are identified and used in the calculations. Copper-containing antifouling paints might contain additional biocides. No specific information on the presence of different biocides in the paints could be retrieved. Diuron and irgarol are defined as the most common biocides added to copper paints[13]. These two substances are therefore included in the assessment of biocide containing paints.

Table 10.7 Antifouling paints per ship and active compounds

Vessel	Paint type	Active antifouling compound
AidaLuna	Silicone, SIGMA Prime 200 / SIGMA Cover 525 / SIGMA Shield 610	None (Hulskotte and Ooms, 2007)
Azura	Silicone, Sigma EcoFLEET 530	Copper and biocide
Caribbean Princess	Silicone, no specifications provided	None (Hulskotte and Ooms, 2007)
Emerald Princess	Silicone, Hempasil Nexus Biocide Free Silicone Type	None (Hulskotte and Ooms, 2007) http://www.hempel.com/en/products/segments/marine/cases/painting-the-emerald-princess)
Grandeur of the Seas	TBT	TBT
Maasdam	Combination of silicon and copper based paint	Copper
Noordam	Copper based	Copper
Ventura	Silicone, BIOCIDAL SIGMA ECOFLEET 530.	Copper and biocide
Westerdam	Copper based	copper
Zuiderdam	Copper based	copper

MAMPEC needs to be fed with emission rates in gram per day. For the antifouling components, the emission is calculated from leaching rates. For copper, the leaching rate is set to 10 $\mu g/cm^2/day$, (Hulskotte *et al.* 2007). For TBT a leaching rate of 2.5 $\mu g/cm^2/day$ is used as proposed by the CEPE Antifouling Working Group as a default value for organic substances in MAMPEC. For diuron and irgarol, leaching rates of 1.5 $\mu g/cm^2/day$ is used (www.emissieregistratie.nl). For ships at berth, the leaching rate is assumed to be 75% of that of sailing ships (Anonymous 2010).

The surface area of the ship's hull that is submerged is needed in order to calculate the emission from the leaching rates. In Table 10.8 the estimates of the surface area are shown. These calculations were done using ship specifications. The leaching rates are listed in Table 10.9.

[12] (http://cfpub.epa.gov/npdes/vessels/vesselsnoisearch.cfm)
[13] (www.emmissregistratie.nl)

Leaching of the compounds in Bonaire's waters during sailing and in the harbour are estimated based on the following assumptions:

Each ship enters Bonaire's water from the territorial water line, 12 nm offshore. A direct route is assumed, resulting in a 2 times 12 nm= 24 nm sailing distance. Based on the average speed of the ship, a total duration of "sailing" is estimated. Duration in the harbour is assumed to be equal for each ship, roughly indicated on experiences that ships come in around 10 AM, and depart at 17 PM, resulting in an average stay of 7 hours per visit. The emission is calculated per visit and per cruise ship season.

Table 10.8 Estimation of the underwater area of the ship's hull. Delphin was not included as no specifications could be found.

Ship	L(ength) [m]	W(idth) [m]	D(raught) [m]	Estimated area under water [m^2]*
AidaLuna	252	38	7.5	13926
Azura	289	50	8.6	20281
Caribbean Princess	290	50	8	19940
Emerald Princess	289	50	7.9	19806
Grandeur of the Seas	280	36	7.6	14883
Maasdam	220	30	7.5	10350
Noordam	291	32	8	14480
Ventura	289	50	8	19874
Westerdam	291	32	8	14480
Zuiderdam	290	32	7.8	14303

* L x W +2(D x (W + L))

Table 10.9 Leaching rates for different anti-fouling components in shipping lane and harbour

Substance[14]	Copper	TBT	Irgarol/Duiron
Leaching rate (sailing) [μg/cm^2/day]	10	1.5	2.5
Leaching rate (berth) [μg/cm^2/day]	7.5	1.9	1.1

Table 10.10 Harbour time per ship in season 2011-2012, based on average 7-hour visit

Ship	frequenting Bonaire season 2011-2012	total stay at port (hours)	total stay at port (days)
AidaLuna	7	49	2.04
Azura	3	21	0.88
Caribbean Princess	12	84	3.5
Emerald Princess	10	70	2.91
Grandeur of the Seas	18	126	5.25
Maasdam	4	28	1.17
Noordam	6	42	1.75
Ventura	3	21	0.88
Westerdam	3	21	0.88
Zuiderdam	11	77	3.21

[14] Copper as copper(I)oxide

Table 10.11 Time in shipping lane, based on 24 nm length per visit

Ship	Frequenting Bonaire season 2011-2012	Speed (km/hour)	Total time in shipping lane (hours)	Total time in shipping lane (days)
AidaLuna	7	40.74	6.64	0.28
Azura	3	43.71	2.65	0.11
Caribbean Princess	12	40.74	11.38	0.47
Emerald Princess	10	39.82	9.70	0.40
Grandeur of the Seas	18	43.52	15.97	0.67
Maasdam	4	40.74	3.79	0.16
Noordam	6	44.45	5.21	0.22
Ventura	3	40.74	2.84	0.12
Westerdam	3	40.74	2.84	0.12
Zuiderdam	11	44.45	9.56	0.40

Table 10.12 Total emission per visit in grams. Total emissions of copper, TBT, diuron and irgarol per ship per visit

Ship	Copper	TBT	Diuron	Irgarol
AidaLuna	0	0	0	0
Azura	518	0	78	78
Caribbean Princess	0	0	0	0
Emerald Princess	0	0	0	0
Grandeur of the Seas	0	95	0	0
Maasdam	267	0	0	0
Noordam	369	0	0	0
Ventura	513	0	77	77
Westerdam	374	0	0	0
Zuiderdam	365	0	0	0

Table 10.13 Total emissions (µgrams) of copper, TBT, diuron and irgarol per ship for season 2011-2012, divided in harbour and shipping lane.

	Copper µg/season		TBT µg/ season		Diuron µg/ season		Irgarol µg/ season	
Ship	Shipping lane	Harbour	Shipping lane	Harbour	Shipping lane	Harbour	Shipping lane	Harbour
AidaLuna	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Azura	224.0	1330.9	0.0	0.0	33.6	199.6	33.6	199.6
Caribbean Princess	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Emerald Princess	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grandeur of the Seas	0.0	0.0	247.7	1465.1	0.0	0.0	0.0	0.0
Maasdam	163.5	905.6	0.0	0.0	0.0	0.0	0.0	0.0
Noordam	314.6	1900.5	0.0	0.0	0.0	0.0	0.0	0.0
Ventura	235.5	1304.2	0.0	0.0	35.3	195.6	35.3	195.6
Westerdam	171.6	950.3	0.0	0.0	0.0	0.0	0.0	0.0
Zuiderdam	569.7	3441.7	0.0	0.0	0.0	0.0	0.0	0.0

Table 10.14 Total emissions (grams) of copper, TBT, diuron and irgarol per ship for season 2011-2012.

Ship	Copper	TBT	Diuron	Irgarol
AidaLuna	0	0	0	0
Azura	1555	0	233	233
delphin				
Caribbean Princess	0	0	0	0
Emerald Princess	0	0	0	0
Grandeur of the Seas	0	1713	0	0
Maasdam	1069	0	0	0
Noordam	2215	0	0	0
Ventura	1540	0	231	231
Westerdam	1122	0	0	0
Zuiderdam	4011	0	0	0

Table 10.15 Total emission (grams) in season 2011-2012, based all vessels and visits summed.

	Copper	TBT	Diuron	irgarol
Total Emission (grams)	11,512	1,713	464	464

Parameterising physical-chemical characteristics for MAMPEC calculations

Chemical-physical properties of toxicants are required to calculate their dispersion in the environment.

Results

Concentrations in the environment

The concentration in the open harbour is parameterised as described above. In table 13 the calculated environmental concentrations are presented, based on maximum, average and the median. These values are based on total concentrations and equal the freely dissolved fraction. The calculations for the concentration are based on a 10 yearlong emission rate. Based on the specific emissions from ships visiting Bonaire in the 2011-2012 season. Table 10.6 lists the properties as collected.

Table 10.16 Physical-chemical properties of emitted substances used for calculations

	Copper(I) oxide*	TBT**	Diuron***	Irgarol****
Henry's const. (Pa m^3/mol)	-	1.52 E-5	5.2 E-5	2E-6
10log(Koc[L/kgOC])	-	3.2	2.7	2.7
10log Kow	-	4.1	2.8	4.1
Kd [m^3/kg]	0.045	220		
Kdeg, boil., sediment [1/day]	-			
Kdeg, boil., water [1/day]	-			
Kdeg, photol., sediment	-			
Kdeg, photol., water [1/day]	-			
Kdeg, abiotic, sediment	-			
Kdeg, abiotic, water [1/day]	-			
Solubility at 20°C [g/m^3]	0.6	4	36.4	6
Sat. vapour pressure [Pa]	2.5 E-7	0.1 mPa	9.2 E-6	8.8 E-5
Molecular weight [g/mol]	143.9	595.6	233.1	253.37

* U.S. Environmental Protection Agency (2008) EPI Suite V4.1
** www.epa.gov/superfund/sites/npl/hrsres/tools/tributyltin_appendix_a.pdf
*** http://www.cdpr.ca.gov/docs/emon/pubs/fatememo/diuron.pdf
**** Aquatic Toxicology 66(2004) 427-444

Table 10.17 Calculated environmental concentrations of copper oxide, TBT, diuron and irgarol.

Parameter	copper	TBT	Diuron	Irgarol
Maximum concentration (µg/L)	0.00032	0.00005	0.00001	0.00001
Average concentration (µg/L)	0.00024	0.00004	0.00001	0.00001
Median concentration (µg/L)	0.00004	0.00001	0.00000	0.00000

Effect concentrations

The EPA database was searched for No Effect Concentrations (NOEC) of the antifouling compounds on corals. The lowest values found are presented in Table 10.18. These No effect concentrations values are much higher(up to factor 100.000) than the calculated concentrations in the environment, and no risk of these concentrations to corals is to be expected.

Table 10.18 Lowest NOEC for diuron, irgarol and copper oxide on coral species. No values found for TBT. Data from EPA database. #; not based on NOEC, but mortality effect.

Compound	Coral species	NOEC (µg/l)	Days	Reference
Diuron	Acropora formosa	0.03	1	Jones,& Kerswell (2003)
Diuron	Acropora tenuis	0.1	10	Watanabe *et al.*, (2006)
Diuron	Acropora valida	0.91	90	Cantin *et al.*, (2007)
Copper oxide	Montipora verrucosa	5.6#	26	Henderson & Salazar (1996)
Irgarol	Madracis mirabilis	0.1	0.3	Owen *et al.*, (2002)
Irgarol	Acropora formosa	0.3	0.4	Jones,& Kerswell (2003)
Irgarol	Madracis mirabilis	10	1	Downs & Downs (2007)

Gaseous emissions

The emissions are estimated using the ship inventory data, the technical characteristic of the ship- engine, speed, load, tonnage and activity data, the fuel consumption. In our study the ship emissions estimated using the methodology of the U.S.A. Environmental Protection Agency. The emissions in this case are expressed by activity data (fuel consumption) and emissions factor for each pollutant per ton of burned fuel. In annex 1 more information is provided of fuel types, fuel use and fuel specifications. This information is however not used in our calculations.

Table 10.19 Formula on estimation of ship emissions

Pollutant	The emissions formula (metric tons/year/ship)
Carbon Dioxide CO_2; Particulate Matter PM; Nitrogen oxide NO_x	
Sulphur dioxide SO_2	

Table 10.20 The emissions rate coefficients (Source: U.S.A. Environmental Protection Agency (EPA, 2002)

Pollutant	Exponential factor	Emissions rate B coefficient	Emissions rate A coefficient
Particulate matter PM	1.5	0.2551	0.0059
Organic Carbon OC	1	0.1548	0.8378
Sulphur dioxide SO2	N/A	-0.4792	2.3735
Nitrogen oxide NOx	1.5	10.4496	0.1255
Carbon Dioxide CO2	1	648.6	44.1

Different actions of the ship ask different power, and result in other emissions. In Table 10.21, the assumed power loads are presented. The % is added as a factor in the standard formula. The duration of each action is estimated and used in the calculation of the emission per visit and season. The emissions of all three sub-emissions were summed to a total emission per ship.

Table 10.21 Power loads per action (%) and assumed duration of the action per visit

Auxiliary power loads	Power loads (kw)	% of full power	duration per visit
Slow/fast cruise	750	80%	Depends on speed
Manoeuvring	1,250	50%	1 hour per visit
At harbour (hoteling)	1,000	20%	7 hours

Table 10.22 Total gaseous emissions in season 2011-2012 per ship

Ship	NO_x (tonnes)	CO_2 (tonnes)	SO_2 (tonnes)
AidaLuna	0.0273	13.79	0.0037
Azura	0.0116	5.910	0.0016
Delphin	0.0092	3.940	0.0017
Caribbean Princess	0.0468	23.64	0.0064
Emerald Princess	0.0391	19.70	0.0053
Grandeur of the Seas	0.0697	35.46	0.0096
Maasdam	0.0156	7.881	0.0033
Noordam	0.0232	11.82	0.0050
Ventura	0.0117	5.910	0.0016
Westerdam	0.0117	5.910	0.0016
Zuiderdam	0.0425	21.67	0.0059
Queen Elizabeth	0.0039	1.970	0.0005

Table 10.23 Background information fuel use: Basic specification per ship to estimate gaseous emission

Ship	Type of Fuel Burned	Installed Power (kW)	Fuel Use (tonnes/day)	Design Speed (knots)	Speed (km/hour)
AidaLuna	MDO	36000	140.00	22.00	40.74
Azura	MDO	67200	279.99	23.60	43.71
delphin	IFO 80	13250	55.21	8.20	15.19
Caribbean Princess	MDO	63360	263.99	22.00	40.74
Emerald Princess	MDO	25000	104.16	21.50	39.82
Grandeur of the Seas	MDO	50400	209.99	23.50	43.52
Maasdam	HFO	34000	141.66	22.00	40.74
Noordam	HFO	28300	216.00	24.00	44.45
Ventura	MDO	29500	122.91	22.00	40.74
Westerdam	MDO	51840	215.99	22.00	40.74
Zuiderdam	Marine Diesel Oil MDO	51840	215.99	24.00	44.45
Queen Elizabeth	MDO	64000	266.66	23.70	43.89

Data from: EPA, 2000. Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data. United States Environmental Pollution Agency, Air and Radiation. EPA420-R-00-002, February 2000.

Table 10.24 The international ISO marine fuel standards

Fuel	Measurement	Limits	INTERNATIONAL ISO STANDARD

Characteristic	units		MGO	IFO-380	MDO	HFO-100
Density	kg/m^3	max	900	991	900	730
Viscosity	mm^2/sb	min max	11.0	180	11.0	991-1010
Sulfur	%(m/m)	max	0.3- 2.0	4.5	2.0	2.0
Ash % mm	%(m/m)	max	0.01	0.15	0.01	0.05

Viscosity (mm^2/s). The viscosity of the fuel (kinematic viscosity). "It is fluidity of the product at a certain temperature. The viscosity of a fuel decreases with increasing temperature. Viscosity outside manufacturers' specific parameters will lead to poor combustion of the fuel, deposit formation and energy loss". Sulfur content (%) – in minimum and maximum percentage Density (kg/m^3) – it is "ignition quality of the fuel within a certain product class". Ash content - it is "measure of the metals present in the fuel, either as inherent to the fuel or as contamination" (Chevron, 2008).