Evaluating anthropogenic risk factors to the Caracol Bay ecosystem

using Habitat Risk Assessment (HRA) models

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Abstract

The need to understand how human activities are affecting ecosystems and the services they provide is becoming a large area of study. This is due to the ever increasing pressures on various habitats from anthropogenic factors; in the case of Caracol Bay, primarily overfishing, charcoal production, and salt pan creation. The Natural Capital Project, a software suite developed to help investors and stakeholders understand the goods and services provided by the environment, was used for this activity to better understand future scenarios that could take place with and without the implementation of improved management practices. This activity has looked at the risks associated from these anthropogenic factors and attempted to visually represent and quantify these impacts while adding a special extent as to where the areas of highest risk are present. The areas with the highest risks were found to be located primarily near residential areas and consisted of disturbances to the mangroves and fisheries. Better management practices need to be initiated in order to protect the environment from human activities. A need for alternate food and fuel sources should also be examined in order to begin to mitigate these impacts.

Background

Caracol Bay is considered by many to be Haiti’s most productive coastal and marine ecosystem. Located in northeastern Haiti near the border with the Dominican Republic and was declared a national park / marine protected area (MPA) in 2013 by the government of Haiti due to its intrinsic values of combined mangrove, seagrass, and coral reef ecosystems. A recent ecosystem services valuation (OAS/FoProBiM, 2013) placed the values of these ecosystems and their services at over US$ 3 billion. This area is also being targeted by several international initiatives including the Caribbean Large Marine Ecosystem (CLME) project, the Caribbean Biological Corridor (CBC), and the Ecologically or Biologically Significant Area (EBSA) activity of the Convention on Biological Diversity.

The need to understand how human activities are and may affect ecosystems and the services they provide is becoming a large area of study. The reason for this is due to the increasing risk to the habitats from anthropogenic factors. Currently over-exploitation of fisheries resources, salt pan development, and mangrove harvesting for charcoal and fuel-wood production are serious concerns to the Caracol Bay area. The recent development of an industrial park near the village of Caracol has raised various alarms concerning the potential damaging effects of this installation and pollution from its various industries on the local ecosystems. Concerns over waste management, increased resource use and destruction, and infrastructure development top these concerns. The monitoring and evaluation of the risks posed by all of these anthropogenic factors to the health and integrity of the local ecosystems are of great concern to the livelihood and wellbeing of local communities.

Ecosystem service is a term used to encompass the ecosystem outputs as a part of the country’s total goods and services value. Stanford University and other private investors have formed an organization called the Natural Capital Project in order to develop models to help map and value goods and services provided by nature that help support human life. The models being used to assess these risks are part of a set of models called InVEST (Integrated Valuation of Environmental Services and Tradeoffs). These models are targeted at designing initiatives which will allow for proper management and policies to be put into place that will have both human and environment components working together in synergy. Though some scenarios do have tradeoffs, the impacts of such tradeoffs can be mitigated by proper planning with the use of these models. This activity primarily uses the Habitat Risk Assessment (HRA) model, which was developed primarily for marine and coastal regions where these impacts are less
understood and in many instances more important. The model outputs can help identify areas where human activities will have the least effects on various habitats so that these ecosystems can prosper without hindering economic development; in short how ecosystem services and development can work together with the least amount of damage to the environment.

**Objectives**

To evaluate the impacts of overfishing, charcoal production, and salt production on mangroves, seagrasses, and coral reefs within Caracol Bay using Habitat Risk Assessment (HRA) models (RIOS, InVEST) with a view towards exploring strategies that would reduce the environmental exposure of the bay to these, and other, stressor activities. It is hoped that the use of these models could be replicated for other locations in Haiti along with the identification and implementation of strategies that would reduce the exposure of a particular habitat to a various harmful activities and would contribute significantly to the overall health of Haiti’s environment.

**Methods**

For the purpose of this study Caracol Bay is characterized into three habitats; mangroves, seagrasses, and coral reefs. Each of these habitats is affected differently by each stressor; salt pans, charcoal production, farming, residential areas, and fishing. In order to best understand the total effect on the Caracol Bay’s environment as a whole, each environment has values that depict how each stressor will affect it. The results are then compiled to display a cumulative risk assessment of the bay.

Anthropogenic impacts to ecosystems / habitats will be modeled using the following steps:

1. **Step 1.** Determine the likelihood of exposure of the habitat to the stressor and the consequence of this exposure.
2. **Step 2.** Combine the exposure and response values to produce a risk value for each stressor-habitat combination.
3. **Step 3.** Quantify the cumulative risk of all stressors on the habitats.
4. **Step 4.** Identify habitats that are risk hotspots. Areas where the influence of human derived stressors is so great that ecosystem structure and function may be compromised (in these areas, there may be trade-offs between human activities and a range of ecosystem services).
5. **Step 5.** Analysis of data to determine which activities are contributing the most to habitat risk /degradation and identify strategies that may reduce the exposure of a particular habitat to a particular activity.

**Risks / Assumptions**

1. There will be adequate access to the software and required applications
2. There will be adequate data for inclusion into the software
3. Field visits will be conducted
4. Users of the site will be interviewed
5. All products generated will be shared with the Government and International Agencies
Model Inputs and Assumptions

The InVEST Habitat Risk Assessment model (HRA) uses the spatial extent of each habitat and stressor as a function of the habitats exposure and the consequences of the exposure from any given stressor (Capital, 2014). The model interprets the interaction between each habitat and stressor by values in the habitat stressor ratings table. This table requires multiple inputs in order to properly represent the habitats ability to grow while also taking into consideration how the stressors will affect each habitat. The values given are based on current and past effects between each habitat and stressor while also taking into consideration research that has been done on similar interactions. More detail on how the model works can be found in the InVEST User Guide, Release 3.0.0 section 4.2 Habitat Risk Assessment.

Definitions from Capital, 2014

Recruitment rating (biotic habitats only).
Frequent recruitment increases recovery potential by increasing the chance that incoming propagules can re-establish a population in a disturbed area.

Natural mortality rate rating (biotic habitats only). Habitats with high natural mortality rates are generally more productive and more capable of recovery.

Connectivity rating (biotic habitats only). Larval dispersal and close spacing of habitat patches increases the recovery potential of a habitat by increasing the chance that incoming propagules can re-establish a population in a disturbed area.

Age at maturity/recovery time. Biotic habitats that reach maturity earlier are likely to be able to recover more quickly from disturbance than those that take longer to reach maturity. Here we refer to maturity of the habitat as a whole (i.e., a mature kelp forest) rather than reproductive maturity of individuals. For abiotic habitats, shorter recovery times for habitats such as mudflats decrease the consequences of exposure to human activities. In contrast, habitats made of bedrock will only recover on geological time scales, greatly increasing the consequences of exposure.
Habitats
The figure below outlines the three habitats which are part of the current study.

![Figure 1: Habitats of Caracol Bay](image)

Mangroves
Mangrove forests have been decreasing rapidly worldwide due to clearing for residential and agricultural initiatives (Duarte, Carlos M., 2009). The importance of the mangrove forests include:
1. Coastal protection from natural disasters by breaking waves
2. Protection for larvae and juvenile fauna to mature
3. Reducing sediment loads from waterways by creating turbulence breaking up laminar flow out to sea
4. Providing sediment retention to assist in the stabilization and seaward expansion of land
5. Carbon sequestration from the air and water
6. Habitat for various types of fauna
Mangroves in the bay will also be affected by the dwindling coastal protection from the coral reef barrier. Pollution, pesticides and sediment from the rivers will also negatively impact the mangroves.

Seagrasses
Seagrasses are a vital component to both faunal habitat and sediment retention. Turbulence created by seagrasses helps particulate settlement creating a suitable bottom for mollusks and other fauna to filter the water. Their root system also helps to maintain the muddy or sandy benthic composition during storms reducing littoral transport away from the bay. Sea turtles and other fauna receive much of their nutrients from seagrass. Seagrass beds are one of the primary location for fish to start the first stage of their life (Mumby, Peter J., 2004).

Coral Reefs
Coral reefs represent some of the most diverse ecosystems in the world. The importance of this ecosystem resides not only in the fauna that inhabit the ecosystem but also for the coastal protection they provide. The fringing reef at Caracol Bay separates the rough mid-water ocean from the calmer seagrass beds. The degradation of this reef caused by overfishing, pollution, and climate change will reduce the protection it provides from ocean waves
including uprooting the seagrass and possibly moving sediment and sand out of the bay. The images below are from the eastern side of the Caracol Bay fringing reef. Notice poor coral structure and almost no fish. The importance of fish, and especially herbivorous fish, on a coral reef is vital to coral growth by limiting algal grown and thereby allowing new coral to grow. The figure to the left below shows the typical structure of the Caracol Bay reef. The figure to the right below shows endangered Elkhorn coral (*Acropora palmata*) that has been stressed and has started to bleach in multiple areas.

![Figure 2: Fringing reef on the eastern part of Caracol Bay. Notice low fish populations, poor coral density and quality.](image)
Stressors
Stressors are the activities affecting the habitat. The figure below displays the current stressors in the Caracol Bay area.

![Stressors in Caracol Bay](image)

Figure 3: Spatial representation of stressors affecting Caracol Bay

Salt Pans
Salt pans utilize shallow water basins and the sun’s heat to evaporate water, leaving behind the salt. The salt is then collected, and the pans then refilled with new saltwater. The pans must be flat, shallow, and have easy access to saltwater to provide the best yields. This environment is very similar to mangrove habitat; thus, in many areas, mangroves are being cleared to make room for more salt pans. The expansion of salt pans is slow, though devastating to the soil quality and would require significant time and effort to rehabilitate.

![Salt Pans in Caracol Bay](image)

Figure 4: Caracol Bay salt pans bordered by once lush black mangroves

Charcoal Production and Deforestation
Mangroves are cut and used for fuel wood and charcoal production; this process can be devastating to mangroves and can completely destroy mangrove forests. Mangroves are also used for wood products needed to build houses, fishing nets, and boats (OAS/FoProBiM, 2013). Because of the services that mangroves provide,
especially in this case wood production, they are also the most at risk from human activities. Values to best represent this interaction have been entered into the models.

![Figure 5: Mangroves being cut along the Caracol Bay canals](image)

![Figure 6: The burning of mangroves for charcoal in north-eastern Caracol Bay](image)

**Fishing**

The effects from over-fishing primarily impact the coral reefs and seagrass habitats. The use of fine mesh nets has increased bycatch and unwanted fish, and has increased the capture of juvenile fish thus having a devastating effect on the local fisheries. Over-fishing reduces fauna around reefs and other coastal systems which rely on the fish for nutrients and algae control.

**Residential and Commercial Areas**

The development of residential and commercial infrastructure can have large impacts on all types of environments. The conversion/clearing of habitats to make way for new and growing sites will drastically change the landscape as well as any habitat which may be impacted. Additional loading from increased human activities must be taken into consideration in these cases. This includes additional sediment erosion in waterways and coastal areas and pollution from poorly managed residential and commercial zones. In order to reduce this impact, areas targeted for construction should be added to the model so as to determine the best positioning for these sites and create protected areas where habitats are the most vulnerable to conversion. Increases in population will create increased stress on the habitats and the environmental services they provide.
Farming
The effects from farming vary greatly based on the crop being farmed and thus the effects of farming on different ecosystems are hard to standardize. Runoff from fertilizers and sediment can have devastating effects on both seagrasses and coral reefs alike.

Figure 7: Left: sediment plume from the Grande Riviere du Nord in western Caracol Bay. Right: sediment plume from the Trou du Nord river in central Caracol Bay
Results
The model outputs can be seen below with a grid cell size of 50 meters. The cumulative risk per habitat (figure 8) displays the risk hotspots with respect only to that particular habitat. From the figure it is clear that the areas nearest the shoreline are the most affected, which is to be expected.

![Cumulative risk assessment per habitat](image)

The cumulative risk (figure 9) displays the sum of all risks in Caracol Bay. Fishing has a large effect on the seagrass and coral reef habitats. The habitats that have the most overlapping stressors are at the highest risk from human activities. Mangroves are the highest risk from human activities because of their location near multiple stressors and their multitude of uses.

![Cumulative Risk Assessment for Caracol Bay](image)
The recovery potential (figure 10) of the habitats is still very high, near 100%, because Caracol bay is still a very productive habitat that has seen very little human impact over time. The recovery potential displays the amount of regrowth/recovery by natural causes if human activities were removed.

Figure 10: Cumulative recovery per habitat

Figure 11 shows the risk for each habitat by consequence and exposure from each stressor (this model is still being formatted by Natural Capital). The higher the consequence the more sensitive the habitat is to the given stressor where higher exposure represents the continuing degradation of a habitat from constant stressors. The purpose of the charts is to help strategize better management practices for the particular habitat and stressor. From the graph, coral reefs are most affected by charcoal production, salt pond intrusion, and primarily, fishing. The mangroves are the most at risk as they are affected by all stressors especially charcoal production and salt pan expansion. Seagrasses are affected by salt pans and their expansion, charcoal production, and fishing.
There was only one area of interest for this study, Caracol bay. For future studies it would be informative to classify multiple areas in Haiti in order to understand habitats at more risk than others.

Figure 12: Overall risk for Caracol Bay
Future Models
Currently the data for Caracol Bay as well as much of Haiti is very limited. This has made even the simplest of models hard to represent accurately. From limited available data assumptions on soil and water velocity vectors were used to put together a general basis for runoff from the Caracol Industrial Park (CIP). Figure 13 below shows the potential impacts of a small oil spill specifically for the Trou du Nord river, which runs through the CIP.

Figure 13: Water quality model displaying oil concentration from the Caracol Industrial Park.

Limitations and Conclusion
Caracol Bay is in need of better management practices. A management plan along with required enforcement needs to be implemented in order to ensure the survival of this ecosystem and the people who rely on it. The mangroves are being cut for charcoal production and a strategy to educate local stakeholders while providing alternatives and replanting activities have not yet been fully implemented. There are very few birds inhabiting the large expanse of mangroves present and the fish biomass in Caracol Bay has been reduced to such low levels that fish over six inches in length are difficult to find while scuba diving in the best parts of the reef. Poor fishing methods and no management policies are to blame for such a small fish biomass.

The biggest limiting factor of this study is the lack of data for Haiti. Any fish biomass data on current capture sizes and weights would help estimate population statistics. This would help represent the growth of fish populations for better management practices. Coastal protection models could be used to better value the mangroves and coral reefs as natural defenses from storms and tsunamis. Data on fishing areas would help to clarify which areas are the most at risk from human interaction. A better understanding of how the habitats and stressors interact should lead to more accurate HRA outputs. Having stronger base data would aid in calculating monetary increases and losses from varying management practices.
Resources


Appendix
Scoring the Habitat
HABITAT NAME: CB_CoralReef_1

HABITAT ONLY PROPERTIES

Rating
recruitment rate
<enter (3) every 2+ yrs, (2) every 1-2 yrs, (1) every <1 yrs, or (0) no score>
natural mortality rate
<enter (3) 0-20%, (2) 20-50%, (1) >80% mortality, or (0) no score>
connectivity rate
<enter (3) <10km, (2) 10-100km, (1) >100km, or (0) no score>
recovery time
<enter (3) >10 yrs, (2) 1-10 yrs, (1) <1 yr, or (0) no score>

HABITAT STRESSOR OVERLAP PROPERTIES

CB_CoralReef_1/CB_Charcoal_2
OVERLAP

Rating
frequency of disturbance
<enter (3) Annually or less often, (2) Several times per year, (1) Weekly or more often, (0) no score>
change in area rating
<enter (3) 50-100% loss, (2) 20-50% loss, (1) 0-20% loss, (0) no score>
change in structure rating
<enter (3) 50-100% loss, (2) 20-50% loss, (1) 0-20% loss, (0) no score>
temporal overlap rating
<enter (3) co-occur 8-12 mo/year, (2) 4-8 mo/yr, (1) 0-4 mo/yr, (0) no score>
management effectiveness
<enter (3) not effective, (2) somewhat effective, (1) very effective, (0) no score>
intensity rating
<enter (3) high, (2) medium, (1) low, (0) no score>

Coral Reef Habitat Stressor Ratings
HABITAT NAME: CB_CoralReef_1

HABITAT ONLY PROPERTIES

Rating | DQ | Weight | E/C
---|---|---|---
recruitment rate | 1 | 2 | 2 | C
natural mortality rate | 3 | 2 | 2 | C
connectivity rate | 3 | 2 | 2 | C
recovery time | 3 | 2 | 2 | C
HABITAT STRESSOR OVERLAP PROPERTIES

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Each table displays values on a per-habitat basis. For each overlapping stressor within the model, the averages for the desired sub-regions are presented. C, E, and Risk values are calculated as an average across a given subregion. Risk Percentage is calculated as a function of total potential risk within that area.
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