RIOS

EVALUATING RISKS TO THE NEWCASTLE BAY LAGOON FROM ANTHROPOGENIC FACTORS

2014

RIOS
Resource Investment Optimization System Project

Evaluating the risk to the Newcastle Bay Lagoon (and by extension the *proposed Narrows MPA*) from anthropogenic factors, using the RIOS Habitat Risk Assessment model

Implementing Agency
The **Organization of American States (OAS)**
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Collaborating Agency
The **Nevis Department of Fisheries**

Contractor
Caribbean Development and Environmental Consultants, Inc. (CADENCO)

2014

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Glossary

CATS	Caribbean Aqua-Terrestrial Solutions Project
CERMES	Centre for Resource Management and Environmental Studies
ECMMAN	Eastern Caribbean Marine Management Area Network
HRA	Habitat Risk Assessment
InVEST	Integrated Valuation of Environmental Services and Tradeoffs
MMA	Marine Management Area
MPA	Marine Protected Area
NBL	Newcastle Bay Lagoon
OAS	Organization of American States
RIOS	Resource Investment Optimization System
SocMon	Socioeconomic Monitoring
TNC	The Nature Conservancy

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Executive Summary

I. Introduction

The Narrows has been identified as an area for conservation and has been proposed as a Marine Protected Area (MPA) for St. Kitts and Nevis, primarily because of the dense seagrass habitat and biodiversity which exists there.

The Narrows is characterized by large sea grass beds (Figure1) which serve as a vital breeding ground and nursery area for several commercially important marine species and an array of other marine species. The seagrass communities are typically co-dominated by turtle grass (*Thalassia testudinum*) and manatee grass (*Syringodium filiforme*). The site also includes areas of the endangered Elkhorn coral (*Acropora palmata*), flat gorgonian hardgrounds and some hard coral framework. Both the coral reef and sea grass communities provide habitat for commercially important fish species, primarily spiny lobster (*Panulirus argus*), and queen conch (*Strombus gigas*), which depend upon both habitats at certain periods in their life cycles. The site produces nutrients that are important in sustaining the life of fish species and other organisms, and reefs that act as barriers during periods of heavy wave attack.

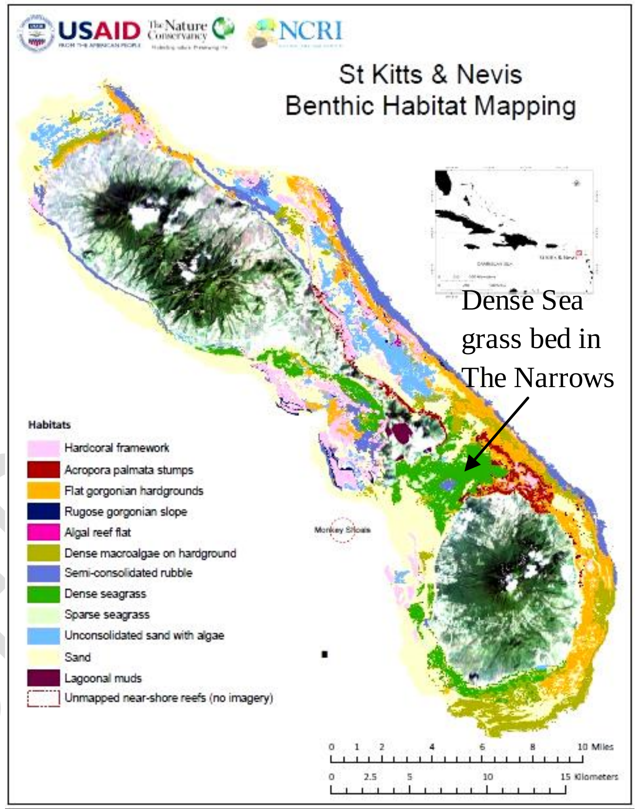


Figure 1. St. Kitts and Nevis Benthic Habitat Map

On the island of Nevis there is a system of freshwater lagoons, some of which are along the coast and are therefore subject to saltwater intrusion. The Newcastle Bay Lagoon is part of the coastal ecosystem on Nevis' North coast, which directly contributes to the health of the resources in The Narrows.

The InVEST Habitat Risk Assessment model evaluates risks posed to coastal and marine habitats in terms of exposure to human activities and the habitat-specific consequence of that exposure for delivery of environmental services. The model can be employed to screen habitat risks under current and future scenarios of use, helping inform management strategies to minimize the impairment of habitat quality and function.

II. Study Area

The Narrows is a marine area located between the Southeast Peninsula of St. Kitts and the North coast of Nevis.

In 2008, the CERMES sponsored socio-economic (SocMon) monitoring program focused on The Narrows area to collect baseline socio-economic data. The SocMon study area is shown in Figure 2. The location of the NBL is shown as a star on this map. Analyses of the SocMon data indicate that fishing is the most important activity in The Narrows and it is also a traditional area for harvesting lobster, conch and finfish. Turtle nesting beaches are located on the sandy beaches along The Narrows coastline, both in St. Kitts and Nevis. Tourism is the second major social and economic activity, which is developing rapidly with the main activities including snorkeling, scuba diving, kayaking, and sport fishing. The fishing and other tourism-related activities occur throughout the year.

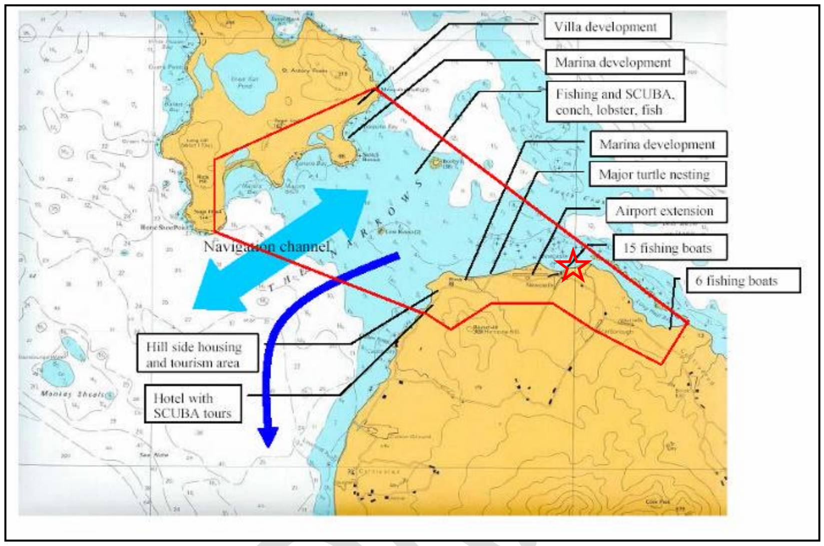


Figure 2. SocMon Study area and location of Newcastle Bay Lagoon

The Narrows is designated as a conservation area in The Nature Conservancy (TNC) draft Marine Zoning Map (2010) (Fig. 3).

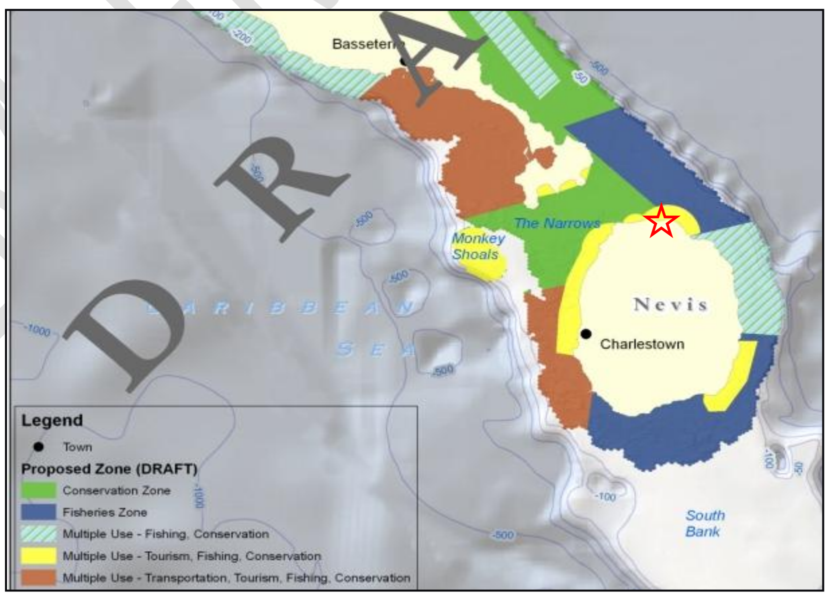


Figure 3. St. Kitts and Nevis Marine Zoning Map (Draft)

Ongoing efforts are being coordinated under the Eastern Caribbean Marine Managed Areas Network (ECMMAN) project to establish a Marine Managed Area (extending two miles out) around the two islands. The Caribbean Aqua-Terrestrial Solutions (CATS) project is currently working on the development of a management Plan for The Narrows MMA and the Sustainable Financing and Management of Eastern Caribbean Marine Ecosystems Project is being developed to provide sustainable funding for the management of The Narrows and other areas with valuable marine resources.

The Newcastle Bay Lagoon is part of the coastal ecosystem on Nevis' North coast; it is located adjacent to the eastern end of the Newcastle Bay, North of the Vance W. Amory Airport runway.

The lagoon system is divided by the fishermen's huts and a road, with a smaller system existing west of the huts and the larger mangrove system existing east of the huts; only the white mangrove species have been documented at the site. The system provides habitat for a variety of invertebrates, crabs and shore birds, such as the great blue and great white herons, moor hens and kingfishers. The system also serves as a nursery for juvenile fish including pelagics such as snook and gars.

Figure 4. Newcastle Bay Lagoon (NBL)

A sandbank and the mangrove system on the eastern end provide some level of protection to the system which remains separate from The Narrows marine environment until there is high tidal action or major storm water flow which breaks the sand bank. Once its sand bank is broken, the biota of the lagoon becomes part of the marine ecosystem within the Narrows. The system protects The Narrows marine environment from over siltation and pollutant loadings in surface runoff. However, there are signs of extensive sedimentation in the lagoon and cutting of mangroves.

Presently Newcastle Bay has many uses which include water sporting activities such as snorkeling, surfing and diving. It is also used for pot and line fishing and is an official fish landing site. Man-made structures that border the bay are the disused Newcastle Jetty, several fishermen's huts, a restaurant as well as at least 3 culverts about 1m in diameter emptying into the bay. The bay is protected by extensive offshore fringing reefs.

III. Project Objective

The objective of this project is to evaluate the risks to the Newcastle Bay Lagoon (and by extension the Proposed Narrows MPA) from anthropogenic factors, using the RIOS Habitat Risk Assessment model, with a view to explore strategies that would reduce the exposure of the Lagoon to a particular stressor activity.

Based on the outcome of implementing the RIOS model at the Newcastle Bay Lagoon, it is envisioned that the model could be applied to other lagoons which discharge into the proposed Narrows MPA, both in St. Kitts and Nevis. The identification and implementation of strategies that would reduce the exposure of a particular habitat to a particular activity would contribute significantly to the overall health of the proposed Narrows MPA.

IV. Identification of Habitats

The condition of a habitat is a key determinant of the environmental services it can provide. In this context Habitat is "a place, or set of places, in which a fish, fish population or fish assemblage finds the physical, chemical and biological features needed for life." The marine ecosystem of The Narrows provides spawning, nursing and feeding areas for most of the country's important coastal fishery species.

The Newcastle Bay lagoon system, which interacts with the sea grass bed and fringing reef in The Narrows off the north coast of Nevis, provides an ecosystem which supports rich biodiversity. However, anthropogenic and natural hazard impact have contributed to some degradation of the system.

Lagoon – (InVEST Soft Bottom)
Soft bottom habitats act as a storage "battery" for nutrients, sediment, and chemicals, cycling them between the bottom and the water column, thus keeping the ecosystem in balance. The lagoon provides a safety haven for juvenile fish to grow until they are flushed into The Narrows. Bottom algae and tiny benthic animals which live in the lagoon provide a vast food supply for the young fish. Mangrove lagoon systems are vital nursery and shoreline protection areas.

Seagrass Bed – (InVEST Eelgrass)
Seagrass forms the base of some biologically rich ecosystems and thus supports many varieties of organisms, including some economically valuable fish and shellfish. Seagrass is a rich source of nourishment and performs many important ecological functions including those listed below:

- Prevents erosion
- Provides safe breeding grounds and nurseries for fish, crustaceans and shellfish
- Slows water flow to promote more photosynthesis
- Provides food for Sea Turtles
- Provides oxygen and detritus

Fringing Reef (InVEST Hard bottom)
Coral reefs and hardbottom communities provide a vital habitat to numerous species of fish and invertebrates, provide protection for coastlines, and are enjoyed for their aesthetic beauty.

Coral reefs require clear warm coastal waters to thrive.

Water Column
The water column provides the basic physical and chemical requirements for aquatic life and links all habitats. Water circulation transports eggs, larvae, food, and oxygen to nursery, spawning and foraging areas.

V. Identification of Stressors

Multiple stressors including fishing, climate change, pollution and coastal development threaten the ability of coastal ecosystems to provide the valuable goods and services that people want and need. As human activities continue to intensify, so too does the need for quick, clear and repeatable ways of assessing the risks posed by human activities under various management plans. Recent global analyses have revealed that almost no area of the world's oceans is untouched by human impacts (Halpern et al. 2008). Thus, an understanding of the location and intensity of human impacts on nearshore ecosystems is an essential component of informed and successful coastal and ocean management.

In 2013 Nevis participated in a ReefFix project to help determine the value of Nevis' ecosystem services. It was highlighted in the project report that Nevis' coastal ecosystems have been increasingly under threat from natural and anthropogenic factors. Threats are primarily associated with natural hazards, illegal development activities, indiscriminate fishing practices, nonpoint source pollution as well as climate change. The valuation of the services which these systems provide helps to raise public awareness and appreciation of the need to effectively manage and protect these systems. The socioeconomic monitoring program reported that the primary problems for marine resources identified by respondents in that study were pollution / garbage and bad fishing practices.

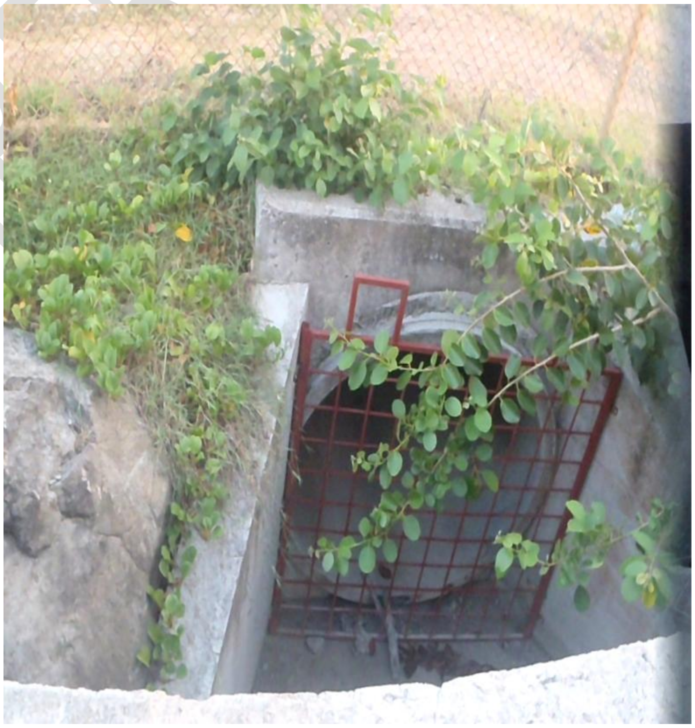
Stressors are the impacts resulting from natural factors or human activities, which in turn affect organisms and ecological processes. The cumulative effects of stressors result in biological responses.

To determine the likelihood of exposure of the habitat to the stressor and the consequence of this exposure, field visits were made to the project site before and after heavy rainfall events. The following observations were made:

- Large amount of debris was found in the drainage channel (ghaut) which empties into the bay through large culverts.
- Large amount of debris was found in and around the lagoon.
- Animals – goats, sheep, pigs, donkeys, dogs - were found grazing and releasing waste into the ghaut and within the area of the lagoon.
- A pig farm is maintained in the mangrove area
- Dirt roads in watershed contribute to sediment laden runoff entering lagoon
- Storm water runoff with pollutants from paved roads and parking lots empties into the lagoon.
- Fishing boats launch and land at the bay. Fish cleaning occurs regularly at the bay.

__Figure 5. Sources of Stressors impacting the Newcastle Bay Lagoon.__

1. Paved Road which drains into the culvert that empties into the Bay. Hydrocarbons, chemicals and sediment are carried in storm water runoff	
2. Goats in Drainage Ghaut. Animal faeces will make its way into the lagoon in storm water runoff.	
3. Storm water culvert which discharges into Bay. Debris is scattered about. This culvert was constructed as part of the airport development works.	

4. Invasive vine which, if not controlled would strangle out other desirable vegetation species	
5. Culvert with drain inlet protection to help prevent rocks and debris from entering the lagoon.	

Sources	**Stressors**	**Example of Biological Responses/ Symptoms**
A. Water Quality Impacts Alteration in hydrology (water diversion, construction)	Increased tidal flow Increased salinity Increased turbidity	-decreased productivity of mangroves, declines in secondary production -mortality of seagrasses if hypersaline conditions persist -loss of habitat to higher trophic levels -numerous secondary effects possible
Coastal nutrification (excess nutrient input)	Increased levels of water column nutrients Oxygen depletion	-increased epiphyte loads on seagrasses -decreased productivity of seagrasses, weakening of root- rhizome systems -shift from benthic to water column productivity in some cases -change in food web structure -hypoxia resulting from decomposition of organic matter
B. Mechanical Impacts Diving and snorkeling	-touching or in some way affecting the bottom -disturbance to fish and other epifauna	-fragmentation, decreased reproductive success, decreased growth, mortality -alteration in behaviour of fishes, may affect grazing and predation
Vessel Groundings	-mechanical impact to the bottom -increased sedimentation	-partial and complete mortality, decreased growth, reduced recruitment -decreased species diversity, abundance, and biomass of epifauna
Harvesting/ fishing Impacts	-removal of organisms from their environment -injury to organisms from fishing methods	-increase in mortality and bioerosion -decrease in diversity, abundance, size, reproductive output -change in species composition and growth

Table 1. Sources of Stressors and Biological responses

The lagoon system is impacted by a number of stressors, but more particularly polluted runoff during heavy rainfall. The runoff follows a natural ghaut upslope, as well as network of drains which together flow into an underground culvert and into the lagoon. When the berm is breached as a result of wave action or increased volume of storm water, the lagoon empties into The Narrows

Constituent in polluted runoff	**Potential sources**	**Effects in water**
Oxygen – demanding substances	Mostly organic materials (feces)	Consume dissolved oxygen
Viruses	Human wastes	Cause diseases (possibly Cancer)
Detergents	Household detergents	Aesthetics, toxic to aquatic life
Phosphates	Detergents	Algal nutrients (eutrophication)
Grease and oil	Food Processing, industrial wastes	Aesthetics, Harmful to some biota
Salts	Human wastes, water softeners	Increase water salinity
Heavy metals	Industrial wastes	Toxicity
Chelating Agents	Some detergents, industrial wastes	Heavy metals ion transport/ solubility
Solids	All sources	Aesthetics (odor, color) harmful to aquatic life

Table 2. Effects of pollutants in marine environment

VI. Habitat Risk Assessment using RIOS

RIOS (Resource Investment Optimization System) is a simple, yet powerful tool that provides a standardized, science-based approach to watershed management. It combines biophysical, social, and economic data to help users identify the best locations for protection and restoration activities in order to maximize the ecological return on investment, within the bounds of what is socially and politically feasible.

Integrated Valuation of Environmental Services and Tradeoffs (InVEST) is a free and open-source software suite designed by RIOS to inform and improve natural resource management and investment decisions. The development of InVEST is an ongoing effort of the Natural Capital Project noting that the original InVEST models were built within ArcGIS but the newest 3.0.1 model is in a standalone form directly launchable from the Windows Operating system, with no other software dependencies. The 3.0.1 InVEST model was used for this assessment.

InVEST currently includes 16 models that analyze different aspects of marine and terrestrial environments **The Habitat Risk Assessment** (HRA) model evaluates the risk to marine or terrestrial habitats from anthropogenic factors. The HRA model in Marine InVEST allows users to evaluate the risk posed by a variety of human activities to key coastal habitats in a transparent, repeatable and flexible way. In the HRA model, *risk is defined as the likelihood that human activities will reduce the quality of nearshore habitats to the point where their ability to deliver environmental services is impaired.*

The risk of human activities to coastal and nearshore habitats is a function of the habitat's exposure to the activity and the consequence of exposure. To determine exposure, users provide model inputs such as base maps of habitat distribution and human activities, the timing and intensity of the activity and the effectiveness of current management practices in safeguarding habitats. To determine consequence, users provide model inputs such as observed loss of habitat and the ability of habitats to recover. The model is flexible and can accommodate data-poor and data-rich situations. Data may come from a combination of peer-reviewed sources at the global scale and locally available fine-scale data sources. Model inputs and results can be updated as better information becomes available.

The HRA model produces information about risk at two scales and with several types of outputs. Maps display variation at a grid cell scale in the relative risk of human activities to habitats within the study area and among alternative future scenarios. Tables and risk plots show the contribution of different activities to the risk posed to each habitat at a sub-regional scale within the study area and among future scenarios.

Details on the methods and system requirements for using the InVEST model can be found in:
InVEST User's Guide. The Natural Capital Project, Stanford. 2014. or ncp-dev.stanford.edu.

Based on the habitat types of the InVEST 3.0.1 Habitat Risk Assessment (HRA) model, the following determinations / inputs were used:

Habitats

Lagoon ....InVEST Soft Bottom
Seagrass Bed ....InVEST Eelgrass

Stressors

Increased sedimentation
Increased nutrients
Increased solids /debris
Removal of Mangroves

Exposure of Habitats to Stressors

a. Spatial overlap – Zone of influence of each stressor
Use maps of habitat and buffered stressors to estimate spatial overlap.

b. Temporal overlap - Duration of time that each habitat is exposed to stressor

c. Intensity rating - Intensity of stressor

d. Management Strategy - Effectiveness of management of each stressor – presence /enforcement of policies, regulations.

Consequence of Exposure

a. Change in area - % change in areal extent of habitat

b. Change in structure - % change in structural density of the habitat

c. Frequency of natural disturbance

d. Natural mortality rate

e. Recruitment rating – Chance that incoming propagules can re-establish a population in a disturbed area.

f. Age at maturity / recovery time

g. Connectivity rating – Distance of Larval dispersal

Table 3. Rankings for evaluating risk of stressors to habitats

	High (3)	Medium (2)	Low (1)	No score (0)
1. Exposure of habitats to stressors				
a. Spatial overlap			Spatial overlap	No spatial overlap
b. Temporal overlap	Habitat and stressor co-occur for 8-12 months of the year	Habitat and stressor co-occur for 4-8 months of the year	Habitat and stressor co-occur for 0-4 months of the year	N/A
c. Intensity	High Intensity	Medium Intensity	Low Intensity	N/A
d. Management effectiveness	Not effective, poorly managed	Somewhat effective	Very effective	N/A
2. Consequences of exposure				
a. Change in area	50 – 100% loss in area	20 – 50% loss in area	0-20% loss in area	N/A
b. Change in structure	For biotic habitats, 50 – 100% loss in density; for abiotic habitats, total structural damage	For biotic habitats 20 – 50% loss in density; for abiotic habitats, partial structural damage	For biotic habitats 0 – 20% loss in density; for abiotic habitats little or no structural damage	N/A
c. Frequency of natural disturbance	Annually or less often	Several times per year	Daily to weekly	N/A
d. Natural mortality rate	0-20%	20 – 50%	80% or higher	N/A
e. Recruitment rate (biotic habitats only)	Every 2+ years	Every 1-2 years	Annual or more often	N/A
f. Age at maturity / recovery time	More than 10 years	1 – 10 years	Less than 1year	N/A
g. Connectivity rating	Low dispersal (less than 10km)	Medium dispersal (10 – 100km)	High dispersal (More than 100km)	N/A
3**. Data Quality**				
For each exposure and consequence score, users can indicate the data that were used to determine the score. *Limited data (1):* No empirical literature exists to justify scoring for the species but a reasonable inference can be made by the user. *Adequate data (2)*: Information is based on data collected outside the study region, may be based on related species, may represent moderate or insignificant statistical relationships. *Best data (3)* : Substantial information is available to support the score and is based on data collected in the study region (or nearby) for the species in question.				

VII. Results

1. Exposure of habitats to stressors

Habitat	Stressor	Spatial Overlap	Temporal Overlap	Intensity	Management Effectiveness
Lagoon	Increased sedimentation	1	3	2	3
Lagoon	Increased nutrients	1	2	3	3
Lagoon	Increased Solids / debris	1	3	2	3
Lagoon	Removal of Mangroves	1	1	1	3
Sea grass	Increased sedimentation	1	1	1	2
Sea grass	Increased Nutrients	1	3	3	3
Sea grass	Increased Solids / debris	0	2	1	2
Sea grass	Removal of Mangroves	0	3	1	3

Table 4. Scores for exposure of habitats to stressors

2. Consequences of exposure

		Change in Area	Change in Structure	Frequency of natural disturbance	Natural mortality rate	Natural recruitment rate	Age at maturity / recovery time	Connectivity (Biotic habitats only)
Habitat	**Stressor**							
Lagoon	Increased sedimentation	3	3	2	2	1	2	3
Lagoon	Increased nutrients	2	3	2	2	1	2	3
Lagoon	Increased Solids / debris	2	2	2	3	1	2	3
Lagoon	Removal of Mangroves	2	2	2	1	1	2	3
Sea grass	Increased sedimentation	1	1	2	3	2	2	2
Sea grass	Increased Nutrients	2	2	2	2	2	3	2
Sea grass	Increased Solids / debris	2	1	1	1	1	1	3
Sea grass	Removal of Mangroves	2	1	2	2	2	3	3

Table 5. Scores for consequences of exposure

3. Calculating Total Risk

It is established that habitats with high exposure to human activities and high consequence are at high risk. The scores assigned to “Exposures” and “Consequences” in the tables above must be verified with pertinent Government agencies.

Efforts to run the InVEST model using the above data to plot exposure and consequence to visualize risk to the habitats associated with the Newcastle Bay Lagoon were not successful. The efforts will continue in an effort to have the map products included in the final report.

The following challenges are noted:

> The preprocessor log and the HRA log for the most recent effort to produce the maps is attached as Annex 1.
>
> Error messages indicate that a more recent version of “Windows Photo Viewer” is required to view the maps.
>
> There is no access to a Subregions Shapefile required in the HRA 3.0 main executable input page.
>
> The risk map generated is shown below and appears to use Barkley Sound as a default location

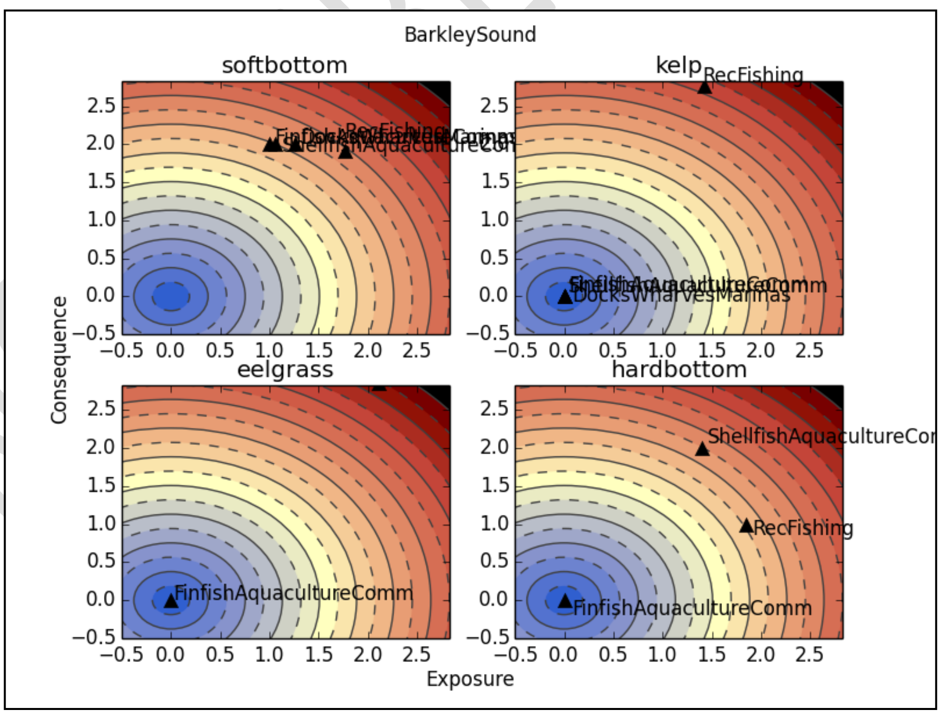


Figure 6. HRA Output for “ Barkley Sound”

VIII. Recommended Mitigation Strategies for Newcastle Bay Lagoon

Habitats	Source of Stressors	Strategies for mitigation
Lagoon system Sea grass	Polluted runoff a. roaming animals	Conduct community awareness about the value of the Mangrove / lagoon system and best practices to minimize stressors to the systems. Educate community on animal control
	b. households	Water testing & monitoring
	Waste Disposal (Garbage)	Organize a community clean up of the ghaut and surroundings and produce education materials on waste management and their negative impact on the habit and overall wellbeing of the environment
	Invasive vegetation	Organize the removal of the invasive plants
	No vegetation around lagoon resulting in exposure to hot temperatures resulting in water loss and habitat loss	Introduce grass that thrives in brackish water and or plant mangroves around the perimeter of the lagoon on the western end. Undertake a mangrove planting initiative in the eastern end of the lagoon

Table 6. Recommended strategies for Mitigation

1. In addition to the strategies listed above, it may be helpful if other species of fish are introduced in the brackish water habitat to render the lagoon more productive. The success of this lagoon could be replicated at other sites around the island and could be a natural resource for persons who are interested in fish farming to obtain fingerlings.
2. There should be continuous monitoring and evaluation of the habitat and stressor interactions through continuous mapping in order to better understand which areas will have the most output from the least investment.
3. The Department of Physical Planning, Natural Resources and Environment should demarcate and map the boundaries and ecological buffer zone of this lagoon and eventually all other lagoons to create an inventory of the “System of Lagoons” in the island.
4. The necessary criteria to have the “System of Lagoons” declared as a protected area should be developed. The declaration will heighten awareness about the environmental services provided by these systems and afford them a more effective management framework.
5. Develop a management plan for the “System of Lagoons” taking into consideration social, ecological and economic impacts.
6. The Department of Physical Planning, Natural Resources and Environment should develop and enforce measures to reduce non-point pollution and minimize cumulative losses to lagoons through voluntary actions, assistance, and incentives.

IX. References

http://sofla-mares.org/docs/MARES_fact%20page_corals.pdf

2014. InVEST User's Guide. The Natural Capital Project, Stanford. 2014.

2010. A. Laurel Arthurton and Karen McDonald. Establishing a socio-economic monitoring program for the Narrows to inform marine conservation and decision-making in St. Kitts and Nevis.

Heather Tallis, Taylor Ricketts, Anne Guerry, Spencer Wood, and Richard Sharp. InVEST 2.6.0 User's Guide: Integrated valuation of Environmental Services and Tradeoff.

Hodge, J. 2013. Nevis ReefFix Report. An OAS Integarated Coastal Zone Management Ecosystem Services Valuation and Capacity Building Project For the Caribbean Project.

ANNEX 1.

Habitat Risk Assessment (HRA) modeling data for Nevis

1. HRA Preprocessor log

Arguments:

exposure_crits [u'Management Effectiveness', u'Temporal Overlap Rating', u'Intensity Rating', u'Spatial Overlap Rating']

habitats_dir C:\InVEST_3_0_1_x86\HabitatRiskAssess\Input\HabitatLayers

resilience_crits [u'Recovery Time']

sensitivity_crits [u'Frequency of Disturbance']

stressors_dir C:\InVEST_3_0_1_x86\HabitatRiskAssess\Input\StressorLayers

workspace_dir C:\InVEST_3_0_1_x86\HabitatRiskAssess\HRA NEVIS

11/13/2014 16:18:00 root INFO Logging will be saved to hra_preprocessor-log-2014-11-13--16_18_00.txt

11/13/2014 16:18:00 root DEBUG Loaded the model from invest_natcap.habitat_risk_assessment.hra_preprocessor

11/13/2014 16:18:00 root INFO Executing the loaded model

11/13/2014 16:18:00 root INFO Running InVEST version "3.0.1"

11/13/2014 16:18:00 root INFO Python architecture: ('32bit', 'WindowsPE')

11/13/2014 16:18:00 root INFO Disk space remaining for workspace: 338.0 GB

11/13/2014 16:18:00 root INFO Pointing temporary directory at the workspace at C:\InVEST_3_0_1_x86\HabitatRiskAssess\HRA NEVIS

11/13/2014 16:18:00 root INFO Updating os.environ["TMP"]=C:\Users\NELCIA~1\AppData\Local\Temp to C:\InVEST_3_0_1_x86\HabitatRiskAssess\HRA NEVIS

11/13/2014 16:18:00 root INFO Updating os.environ["TEMP"]=C:\Users\NELCIA~1\AppData\Local\Temp to C:\InVEST_3_0_1_x86\HabitatRiskAssess\HRA NEVIS

11/13/2014 16:18:00 root INFO Setting os.environ["TMPDIR"]=C:\InVEST_3_0_1_x86\HabitatRiskAssess\HRA NEVIS

11/13/2014 16:18:00 root INFO Starting hra_preprocessor

11/13/2014 16:18:00 root INFO Opening file explorer to workspace directory

11/13/2014 16:18:00 root INFO Using windows explorer to view files

11/13/2014 16:18:00 root INFO Disk space free: 338.0 GB

11/13/2014 16:18:00 root INFO Elapsed time: 0

2. HRA log

Arguments:

aoi_tables C:\InVEST_3_0_1_x86\HabitatRiskAssess\Input\subregions.shp

csv_uri C:\InVEST_3_0_1_x86\HabitatRiskAssess\NEV\habitat_stressor_ratings

decay_eq Linear

grid_size 500

max_rating 3

max_stress 4

risk_eq Euclidean

workspace_dir C:\InVEST_3_0_1_x86\HabitatRiskAssess\HRA NEVIS

11/13/2014 16:20:40 root INFO Logging will be saved to hra-log-2014-11-13--16_20_40.txt

11/13/2014 16:20:40 root DEBUG Loaded the model from invest_natcap.habitat_risk_assessment.hra

11/13/2014 16:20:40 root INFO Executing the loaded model

11/13/2014 16:20:40 root INFO Running InVEST version "3.0.1"

11/13/2014 16:20:40 root INFO Python architecture: ('32bit', 'WindowsPE')

11/13/2014 16:20:40 root INFO Disk space remaining for workspace: 338.0 GB

11/13/2014 16:20:40 root INFO Pointing temporary directory at the workspace at C:\InVEST_3_0_1_x86\HabitatRiskAssess\HRA NEVIS

11/13/2014 16:20:40 root INFO Updating os.environ["TMP"]=C:\Users\NELCIA~1\AppData\Local\Temp to C:\InVEST_3_0_1_x86\HabitatRiskAssess\HRA NEVIS

11/13/2014 16:20:40 root INFO Updating os.environ["TEMP"]=C:\Users\NELCIA~1\AppData\Local\Temp to C:\InVEST_3_0_1_x86\HabitatRiskAssess\HRA NEVIS

11/13/2014 16:20:40 root INFO Setting os.environ["TMPDIR"]=C:\InVEST_3_0_1_x86\HabitatRiskAssess\HRA NEVIS

11/13/2014 16:20:40 root INFO Starting hra

11/13/2014 16:20:41 HRA_PREPROCESSOR DEBUG ['DocksWharvesMarinas', '0']

11/13/2014 16:20:41 HRA_PREPROCESSOR DEBUG ['FinfishAquacultureComm', '0']

```
11/13/2014 16:20:41  HRA_PREPROCESSOR   DEBUG    ['RecFishing', '0']

11/13/2014 16:20:41  HRA_PREPROCESSOR   DEBUG    ['ShellfishAquacultureComm', '0']

11/13/2014 16:20:41  HRA              INFO     Rasterizing shapefile layers.

11/13/2014 16:20:46  HRA_CORE         INFO     Applying CSV criteria to rasters.

11/13/2014 16:20:50  HRA_CORE         INFO     Calculating risk rasters for individual overlaps.

11/13/2014 16:21:01  HRA_CORE         INFO     Calculating habitat risk rasters.

11/13/2014 16:21:02  HRA_CORE         INFO     Making risk shapefiles.

11/13/2014 16:21:07  HRA_CORE         INFO     Calculating ecosystem risk rasters.

11/13/2014 16:21:08  HRA_CORE         INFO     Creating subregion maps and risk plots.

11/13/2014 16:21:10  HRA_CORE         DEBUG    arb_uri:
C:\InVEST_3_0_1_x86\HabitatRiskAssess\HRA
NEVIS\intermediate\H[softbottom]_S[DocksWharvesMarinas]_Risk.tif

11/13/2014 16:21:11  HRA_CORE         DEBUG    Entering new funct.

11/13/2014 16:21:11  HRA_CORE         DEBUG    softbottom,DocksWharvesMarinas:defaultdict(<function
<lambda> at 0x06AB20F0>, {0.0: defaultdict(<function <lambda> at 0x06AB2130>, {'H': [1586, 1586.0], 'C':
[1586, 3172.0], 'E': [14, 21.0], 'H_S': [14, 14.0]}), 1.0: defaultdict(<function <lambda> at 0x06AB2170>, {'H':
[3719, 3719.0], 'C': [3719, 7438.0], 'E': [9, 13.5], 'H_S': [9, 9.0]})})

11/13/2014 16:21:11  HRA_CORE         DEBUG    Exiting new funct.

11/13/2014 16:21:11  HRA_CORE         DEBUG    Entering new funct.

11/13/2014 16:21:12  HRA_CORE         DEBUG    kelp,RecFishing:defaultdict(<function <lambda> at
0x06AB22F0>, {0.0: defaultdict(<function <lambda> at 0x06AB2330>, {'H': [239, 239.0], 'C': [239, 662.0],
'E': [110, 110.0], 'H_S': [110, 110.0]}), 1.0: defaultdict(<function <lambda> at 0x06AB2370>, {'H': [289,
289.0], 'C': [289, 825.5], 'E': [83, 83.0], 'H_S': [83, 83.0]})})

11/13/2014 16:21:12  HRA_CORE         DEBUG    Exiting new funct.

11/13/2014 16:21:12  HRA_CORE         DEBUG    Entering new funct.

11/13/2014 16:21:12  HRA_CORE         DEBUG
softbottom,ShellfishAquacultureComm:defaultdict(<function <lambda> at 0x06AB2430>, {0.0:
defaultdict(<function <lambda> at 0x06AB2470>, {'H': [1586, 1586.0], 'C': [1586, 3172.0], 'E': [108, 108.0],
'H_S': [100, 100.0]}), 1.0: defaultdict(<function <lambda> at 0x06AB24B0>, {'H': [3719, 3719.0], 'C': [3719,
7438.0], 'E': [32, 32.0], 'H_S': [32, 32.0]})})

11/13/2014 16:21:12  HRA_CORE         DEBUG    Exiting new funct.

11/13/2014 16:21:12  HRA_CORE         DEBUG    Entering new funct.
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11/13/2014 16:21:12 HRA_CORE DEBUG hardbottom,RecFishing:defaultdict(<function <lambda> at 0x06AB2570>, {0.0: defaultdict(<function <lambda> at 0x06AB25B0>, {'H': [1377, 1377.0], 'C': [343, 343.0], 'E': [343, 771.75], 'H_S': [343, 343.0]}), 1.0: defaultdict(<function <lambda> at 0x06AB25F0>, {'H': [491, 491.0], 'C': [213, 213.0], 'E': [213, 479.25], 'H_S': [213, 213.0]})})

11/13/2014 16:21:12 HRA_CORE DEBUG Exiting new funct.

11/13/2014 16:21:12 HRA_CORE DEBUG Entering new funct.

11/13/2014 16:21:12 HRA_CORE DEBUG hardbottom,FinfishAquacultureComm:defaultdict(<function <lambda> at 0x06AB26B0>, {0.0: defaultdict(<function <lambda> at 0x06AB26F0>, {'H': [1377, 1377.0], 'C': [0, 0.0], 'E': [0, 0.0], 'H_S': [0, 0.0]}), 1.0: defaultdict(<function <lambda> at 0x06AB2730>, {'H': [491, 491.0], 'C': [0, 0.0], 'E': [0, 0.0], 'H_S': [0, 0.0]})})

11/13/2014 16:21:12 HRA_CORE DEBUG Exiting new funct.

11/13/2014 16:21:12 HRA_CORE DEBUG Entering new funct.

11/13/2014 16:21:13 HRA_CORE DEBUG kelp,DocksWharvesMarinas:defaultdict(<function <lambda> at 0x06AB27F0>, {0.0: defaultdict(<function <lambda> at 0x06AB2830>, {'H': [239, 239.0], 'C': [239, 717.0], 'E': [0, 0.0], 'H_S': [0, 0.0]}), 1.0: defaultdict(<function <lambda> at 0x06AB2870>, {'H': [289, 289.0], 'C': [289, 864.0], 'E': [2, 5.2000002861022949], 'H_S': [2, 2.0]})})

11/13/2014 16:21:13 HRA_CORE DEBUG Exiting new funct.

11/13/2014 16:21:13 HRA_CORE DEBUG Entering new funct.

11/13/2014 16:21:13 HRA_CORE DEBUG kelp,ShellfishAquacultureComm:defaultdict(<function <lambda> at 0x06AB2930>, {0.0: defaultdict(<function <lambda> at 0x06AB2970>, {'H': [239, 239.0], 'C': [239, 717.0], 'E': [0, 0.0], 'H_S': [0, 0.0]}), 1.0: defaultdict(<function <lambda> at 0x06AB29B0>, {'H': [289, 289.0], 'C': [289, 867.0], 'E': [0, 0.0], 'H_S': [0, 0.0]})})

11/13/2014 16:21:13 HRA_CORE DEBUG Exiting new funct.

11/13/2014 16:21:13 HRA_CORE DEBUG Entering new funct.

11/13/2014 16:21:13 HRA_CORE DEBUG softbottom,FinfishAquacultureComm:defaultdict(<function <lambda> at 0x06AB2A70>, {0.0: defaultdict(<function <lambda> at 0x06AB2AB0>, {'H': [1586, 1586.0], 'C': [1586, 3172.0], 'E': [8, 8.0], 'H_S': [8, 8.0]}), 1.0: defaultdict(<function <lambda> at 0x06AB2AF0>, {'H': [3719, 3719.0], 'C': [3719, 7438.0], 'E': [108, 108.0], 'H_S': [108, 108.0]})})

11/13/2014 16:21:13 HRA_CORE DEBUG Exiting new funct.

11/13/2014 16:21:13 HRA_CORE DEBUG Entering new funct.

11/13/2014 16:21:13 HRA_CORE DEBUG kelp,FinfishAquacultureComm:defaultdict(<function <lambda> at 0x06AB2BB0>, {0.0: defaultdict(<function <lambda> at 0x06AB2BF0>, {'H': [239, 239.0], 'C': [239, 717.0], 'E': [8, 8.0], 'H_S': [0, 0.0]}), 1.0: defaultdict(<function <lambda> at 0x06AB2C30>, {'H': [289, 289.0], 'C': [289, 867.0], 'E': [108, 108.0], 'H_S': [4, 4.0]})})

11/13/2014 16:21:13 HRA_CORE DEBUG Exiting new funct.

11/13/2014 16:21:13 HRA_CORE DEBUG Entering new funct.

11/13/2014 16:21:14 HRA_CORE DEBUG eelgrass,RecFishing:defaultdict(<function <lambda> at 0x06AB2CF0>, {0.0: defaultdict(<function <lambda> at 0x06AB2D30>, {'H': [418, 418.0], 'C': [418, 1192.7999975681305], 'E': [51, 153.0], 'H_S': [51, 51.0]}), 1.0: defaultdict(<function <lambda> at 0x06AB2D70>, {'H': [921, 921.0], 'C': [921, 2615.399994134903], 'E': [123, 369.0], 'H_S': [123, 123.0]})})

11/13/2014 16:21:14 HRA_CORE DEBUG Exiting new funct.

11/13/2014 16:21:14 HRA_CORE DEBUG Entering new funct.

11/13/2014 16:21:14 HRA_CORE DEBUG eelgrass,DocksWharvesMarinas:defaultdict(<function <lambda> at 0x06AB2E30>, {0.0: defaultdict(<function <lambda> at 0x06AB2E70>, {'H': [418, 418.0], 'C': [418, 1245.0], 'E': [6, 14.40000057220459], 'H_S': [6, 6.0]}), 1.0: defaultdict(<function <lambda> at 0x06AB2EB0>, {'H': [921, 921.0], 'C': [921, 2751.0], 'E': [8, 19.200000762939453], 'H_S': [8, 8.0]})})

11/13/2014 16:21:14 HRA_CORE DEBUG Exiting new funct.

11/13/2014 16:21:14 HRA_CORE DEBUG Entering new funct.

11/13/2014 16:21:15 HRA_CORE DEBUG eelgrass,ShellfishAquacultureComm:defaultdict(<function <lambda> at 0x06AB2F70>, {0.0: defaultdict(<function <lambda> at 0x06ABA070>, {'H': [418, 418.0], 'C': [418, 1254.0], 'E': [108, 108.0], 'H_S': [46, 46.0]}), 1.0: defaultdict(<function <lambda> at 0x06AB2FB0>, {'H': [921, 921.0], 'C': [921, 2763.0], 'E': [32, 32.0], 'H_S': [12, 12.0]})})

11/13/2014 16:21:15 HRA_CORE DEBUG Exiting new funct.

11/13/2014 16:21:15 HRA_CORE DEBUG Entering new funct.

11/13/2014 16:21:15 HRA_CORE DEBUG softbottom,RecFishing:defaultdict(<function <lambda> at 0x06ABA0F0>, {0.0: defaultdict(<function <lambda> at 0x06ABA130>, {'H': [1586, 1586.0], 'C': [1586, 3024.399994134903], 'E': [246, 553.5], 'H_S': [246, 246.0]}), 1.0: defaultdict(<function <lambda> at 0x06ABA170>, {'H': [3719, 3719.0], 'C': [3719, 7058.7999849319458], 'E': [632, 1422.0], 'H_S': [632, 632.0]})})

11/13/2014 16:21:15 HRA_CORE DEBUG Exiting new funct.

11/13/2014 16:21:15 HRA_CORE DEBUG Entering new funct.

11/13/2014 16:21:15 HRA_CORE DEBUG hardbottom,ShellfishAquacultureComm:defaultdict(<function <lambda> at 0x06ABA230>, {0.0: defaultdict(<function <lambda> at 0x06ABA270>, {'H': [1377, 1377.0], 'C': [7, 14.0], 'E': [7, 12.599999666213989], 'H_S': [7, 7.0]}), 1.0: defaultdict(<function <lambda> at 0x06ABA2B0>, {'H': [491, 491.0], 'C': [0, 0.0], 'E': [0, 0.0], 'H_S': [0, 0.0]})})

11/13/2014 16:21:15 HRA_CORE DEBUG Exiting new funct.

11/13/2014 16:21:15 HRA_CORE DEBUG Entering new funct.

11/13/2014 16:21:16 HRA_CORE DEBUG eelgrass,FinfishAquacultureComm:defaultdict(<function <lambda> at 0x06ABA370>, {0.0: defaultdict(<function <lambda> at 0x06ABA3B0>, {'H': [418, 418.0], 'C': [418, 1254.0], 'E': [8, 8.0], 'H_S': [0, 0.0]}), 1.0: defaultdict(<function <lambda> at 0x06ABA3F0>, {'H': [921, 921.0], 'C': [921, 2763.0], 'E': [108, 108.0], 'H_S': [7, 7.0]})})

11/13/2014 16:21:16 HRA_CORE DEBUG Exiting new funct.

11/13/2014 16:21:16 HRA_CORE DEBUG Entering new funct.

11/13/2014 16:21:16 HRA_CORE DEBUG hardbottom,DocksWharvesMarinas:defaultdict(<function <lambda> at 0x06ABA4B0>, {0.0: defaultdict(<function <lambda> at 0x06ABA4F0>, {'H': [1377, 1377.0], 'C': [8, 24.0], 'E': [8, 10.0], 'H_S': [8, 8.0]}), 1.0: defaultdict(<function <lambda> at 0x06ABA530>, {'H': [491, 491.0], 'C': [0, 0.0], 'E': [0, 0.0], 'H_S': [0, 0.0]})})

11/13/2014 16:21:16 HRA_CORE DEBUG Exiting new funct.

11/13/2014 16:21:16 HRA_CORE DEBUG AOI list for ClaySound: [('hardbottom', 'DocksWharvesMarinas', 0.0, 0.0, 0.0, 0.0), ('hardbottom', 'RecFishing', 2.021593663514194, 1.0, 1.021593663514194, 1.0), ('hardbottom', 'FinfishAquacultureComm', 0.0, 0.0, 0.0, 0.0), ('hardbottom', 'ShellfishAquacultureComm', 0.0, 0.0, 0.0, 0.0), ('softbottom', 'DocksWharvesMarinas', 1.2522124017373912, 2.0, 1.031315226102157, 0.24430541357609775), ('softbottom', 'ShellfishAquacultureComm', 1.0078663172885021, 2.0, 1.0000309389952309, 0.23689456526643274), ('softbottom', 'FinfishAquacultureComm', 1.0265488208486944, 2.0, 1.0003523578661953, 0.2369707052944423), ('softbottom', 'RecFishing', 1.7803597664479152, 1.8980371026974847, 1.1897192958475278, 0.2818293158630272), ('kelp', 'DocksWharvesMarinas', 1.806326808981443, 2.9896193771626298, 2.1467995222803657, 0.3565095626949463), ('kelp', 'RecFishing', 1.2625596044185707, 2.8564013840830449, 1.8748769678829278, 0.3113525790320522), ('kelp', 'FinfishAquacultureComm', 1.0126534749117382, 3.0, 2.0000400272062913, 0.33213785827300146), ('kelp', 'ShellfishAquacultureComm', 0.0, 0.0, 0.0, 0.0), ('eelgrass', 'DocksWharvesMarinas', 1.7079410992569892, 2.9869706840390879, 2.1093205302295703, 0.2552327859477878), ('eelgrass', 'RecFishing', 2.1220936679390778, 2.8397394073125981, 2.1549327800300135, 0.26075197633306624), ('eelgrass', 'FinfishAquacultureComm', 1.0069484201266143, 3.0, 2.000012070099142, 0.2420062030710187), ('eelgrass', 'ShellfishAquacultureComm', 1.0119115773599101, 3.0, 2.0000354711042503, 0.24200903464812715)]

11/13/2014 16:21:18 HRA_CORE DEBUG AOI list for BarkleySound: [('hardbottom', 'DocksWharvesMarinas', 1.1303113351481371, 3.0, 2.0042407649950866, 0.5092422048848562), ('hardbottom', 'RecFishing', 1.8527234944763773, 1.0, 0.8527234944763773, 0.21666198995076041), ('hardbottom', 'FinfishAquacultureComm', 0.0, 0.0, 0.0, 0.0), ('hardbottom', 'ShellfishAquacultureComm', 1.4046473944127622, 2.0, 1.078767590264482, 0.27409580516438337), ('softbottom', 'DocksWharvesMarinas', 1.2580699810045544, 2.0, 1.0327633393453173, 0.24460976400965873), ('softbottom', 'ShellfishAquacultureComm', 1.0576427214611031, 2.0, 1.001659963928599, 0.23724293655680762), ('softbottom', 'FinfishAquacultureComm', 1.0046114177168883, 2.0, 1.0000106325301543, 0.23685229278705197), ('softbottom', 'RecFishing', 1.7668010947943136, 1.9069356835655127, 1.1876515705804467, 0.28129500664648166), ('kelp', 'DocksWharvesMarinas', 0.0, 0.0, 0.0, 0.0), ('kelp', 'RecFishing', 1.4207677483725543, 2.7698744769874475, 1.8192034417189573, 1.0), ('kelp', 'FinfishAquacultureComm', 0.0, 0.0, 0.0, 0.0), ('kelp',

'ShellfishAquacultureComm', 0.0, 0.0, 0.0, 0.0), ('eelgrass', 'DocksWharvesMarinas', 1.7131227303972052, 2.9784688995215309, 2.1030651951337846, 0.33558209355414836), ('eelgrass', 'RecFishing', 2.1115428030646601, 2.8535885109285419, 2.1613231528142967, 0.344878204511551), ('eelgrass', 'FinfishAquacultureComm', 0.0, 0.0, 0.0, 0.0), ('eelgrass', 'ShellfishAquacultureComm', 1.1006072341367521, 3.0, 2.002528855113116, 0.31953970193430065)]

11/13/2014 16:21:19 HRA_CORE WARNING Please note that the (softbottom, ShellfishAquacultureComm) is being run with insufficient data. We recommend entering criteria scores for both exposure and consequence.

11/13/2014 16:21:19 HRA_CORE WARNING Please note that the (softbottom, FinfishAquacultureComm) is being run with insufficient data. We recommend entering criteria scores for both exposure and consequence.

11/13/2014 16:21:19 HRA_CORE WARNING Please note that the (kelp, FinfishAquacultureComm) is being run with insufficient data. We recommend entering criteria scores for both exposure and consequence.

11/13/2014 16:21:19 HRA_CORE WARNING Please note that the (eelgrass, ShellfishAquacultureComm) is being run with insufficient data. We recommend entering criteria scores for both exposure and consequence.

11/13/2014 16:21:19 HRA_CORE WARNING Please note that the (eelgrass, FinfishAquacultureComm) is being run with insufficient data. We recommend entering criteria scores for both exposure and consequence.

11/13/2014 16:21:19 root INFO Opening file explorer to workspace directory

11/13/2014 16:21:19 root INFO Using windows explorer to view files

11/13/2014 16:21:19 root INFO Disk space free: 338.0 GB

11/13/2014 16:21:19 root INFO Elapsed time: 38.79s

11/13/2014 16:21:19 root