Final Report

Literature Review of the Pellicer Watershed Economic Valuation and Assessment Study

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By:
The Center for Economic Forecasting and Analysis,
Florida State University

Submitted to:
The Guana Tolomato Mantanzas National Estuarine Research Reserve

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Introduction

The Florida Department of Environmental Protection (FDEP) Guana Tolomato Matanzas National Estuarine Research Reserve (GTM NERR) contracted with the Florida State University Center for Economic Forecasting and Analysis (FSU CEFA) to conduct an economic analysis study of the Pellicer Watershed. The first step of the study involved a literature review relating to modeling the effects and tradeoffs of different upland land-use scenarios on the Pellicer estuarine ecosystem services (anticipating sea level rise), including the associated data requirements. The Guana Tomato Matanzas National Estuarine Research Reserve (GTM NERR) also requested that FSU CEFA explore the use of the Land Development Intensity Index (LDI) and the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST).

The literature review is divided into 6 sections:

1. Ecosystem Services
2. Land Development Intensity Index (LDI)
3. InVEST
4. Other Land Use Simulation Models
5. Vulnerability Assessment
6. Examples of Economic Valuation Results Used in Decision Making

I. Ecosystem Services

Ecosystem services are the results of the biological, chemical, and physical processes associated with natural estuary environments that benefit human beings.

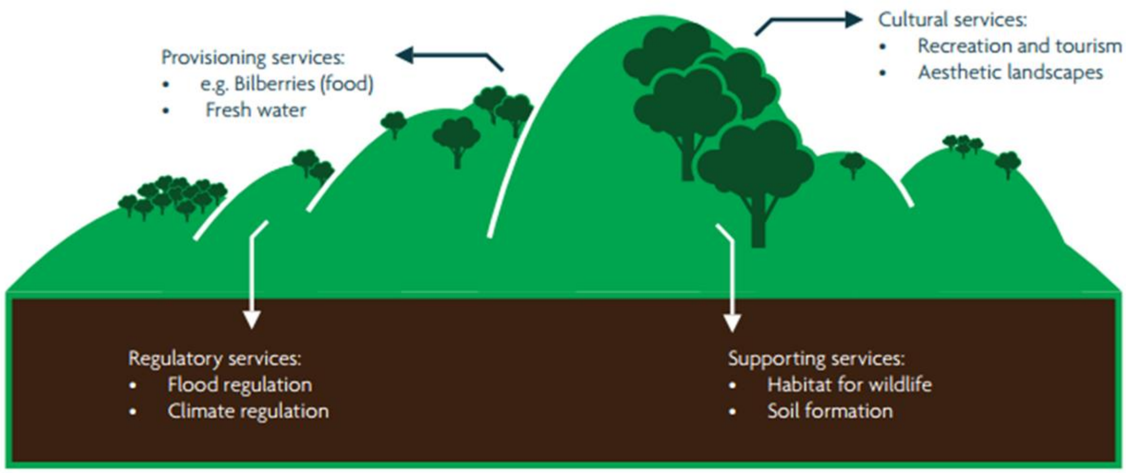

Figure 1. An Example of Ecosystem Services Provided by Upland Areas (South African Water Research Commission)

Figure 1[1] displays ecosystem services provided by upland areas. These ecosystem services fall into four broad categories:

- Provision services which include provision of food, fresh water, building materials, medicinal plants and ornamental plants.
- Cultural (Spiritual and Information Services) services such as recreation, tourism and aesthetic landscapes.
- Regulatory services such as food regulation, climate regulation, soil stability, sediment supply, waste assimilation, disease control, waste dilution, flood attenuation, pest control, fire damage control, and coastal storm damage control.

[1] Extracted from South African Water Research Commission, Introduction to Estuary Ecosystem Services.

- Supporting services such as habitat for wildlife and soil formation, and nutrient cycling.

It is recommended to quantify ecosystem functions with indicators that are able to describe the ecosystem process that provides the service (e.g. total water-storage capacity in m^3) and measure how much of the service that can be sustainably used (e.g. reduction of flood-danger).

One may add an economic dimension by determining values for the ecosystem services, typically in monetary terms. The value of a service is evaluated by measuring the welfare created by the goods produced using these services. There are use values (for example, timber and fish extraction) and non-use values (for example, birdwatching). Use values can be direct or indirect. Direct uses can be divided into consumptive and non-consumptive. Non-use values can be divided into as existence value and bequest value. Existence value is the value that someone places on an ecosystem just because it exists even though that person has no intention to ever use it. Bequest value is that value that someone places on an ecosystem because it will be available for others and for future generations (Forkink, 2015).

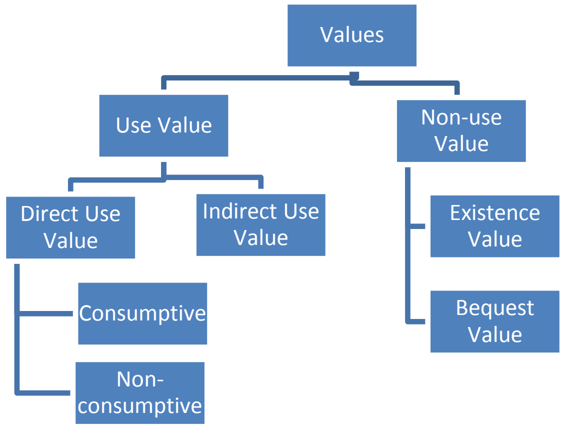

Figure 2. How Values are Categorized

Services can be valued using the market value, shadow pricing or benefit transfer. Market value can be used for services such as provision services where humans are paying for the goods such as food and timber that are obtained from the respective ecosystem service. Shadow pricing is used by measuring the investments made by public and private agencies to protect that ecosystem in order to maintain the ecosystem services from that area. Benefit transfer is done by using data from other studies to create an estimate of the value of the same ecosystem service that is in a different geographical area. Benefit transfer should only be used when: 1) the data in the original study 'are of sufficient quality' 2) the ecosystem services in the studies are very similar, and; 3) the context is very similar (Forkink, 2015).

II. Land Development Intensity Index (LDI)

This section of the literature review focuses on the Land Development Intensity Index that was originally developed by Mark T. Brown and M. Benjamin Vivas from the Center for Environmental Policy at the Department of Environmental Engineering Sciences at the University of Florida. This section summarizes three papers:

1. Landscape Development Intensity Index by Mark T. Brown and M. Benjamin Vivas (2005), which discusses the development of the land development intensity index (LDI).
2. Calculation of Landscape Development Intensity (LDI) Values for Land Use Types in Arkansas and Florida: Lessons Learned by Benjamin Vivas, discusses lessons learned from applying the use of the LDI to the Bayou Meto Watershed (BMW) in Arkansas.
3. Landscape Development Intensity and Pollutant Emergy/Empower Density Indices as Indicators of Ecosystem Health by Mark T. Brown and Kelly Chinners Reiss, which discusses how and why the LDI has been updated, and also introduces the Pollutant Density Index (PDI), and the Pollutant Empower Density index (PED).

A. **A Summary of the Landscape Development Intensity Index by Mark T. Brown and M. Benjamin Vivas (2005)**

What is LDI?

LDI is a method of quantitatively evaluating the human disturbance gradient that is applicable to landscapes of varying scales, from watersheds to forest patches, or isolated wetlands.

The human disturbance gradient is the effect of human land uses of on ecological processes of natural communities (or the quality of ecological communities) measured by the intensity of that human land use.

LDI is measured on a scale of 1 to 10, with 1.0 being the LDI for natural lands and a LDI of 10.0 for the highest intensity land use, the Central Business District.

LDI's Method

1. Delineation of Area of Influence: The area of influence should include all lands that "contribute" to the landscape unit. The writers found that in the absence of any particular landscape feature such as a drainage structure that may direct stormwater into a wetland or water body, a 100 m buffer was adequate to capture surrounding land use effects.

   For large scale units such as rivers, streams, or lakes, delineated coverages of drainage basins often exist as part of GIS databases kept by various agencies of local, state, and federal government.

   For an individual wetland or forest patch, the area of influence is the surrounding landscape and could be delineated as the watershed of the ecosystem, if topographic coverages are available.

2. Characterization of Land Uses: Use existing land use/land cover GIS data from recent spatial data bases to save time, but ensure that it is up to date and verify land uses in the area of influence through ground trothing, or verification, using recent aerial photographs. Digital Orthophoto Quads (DOQ) have been used to good effect for ground truthing land use/land cover data from other sources.

   If these data are not available, land uses can be delineated on aerial photographs (using Table 1 in the literature as a guide for different land uses). In Florida, the most used classification scheme is the Florida Land Use and Cover Classification System (FLUCCS).

Table 1. Land Uses and Definitions

Land use/land cover	Definition
Natural land/open water	Open water, upland, or wetland with very low manipulations (i.e. state parks, refuges, preserves and other protected lands).
Tree plantations	Land devoted to silviculture with varying stocking densities.
Unimproved pastureland	Native rangeland and woodland pasture with presence of livestock.
Improved pasture (no livestock)	Areas where the natural vegetation has been altered by drainage, irrigation, etc., for the grazing of domestic animals. Does not include livestock.
Improved pasture–low-intensity (with livestock)	Areas where the natural vegetation has been altered by drainage, irrigation, etc., for the grazing of domestic animals with a density of less than 1.2 animals/ha.
Improved pasture–high-intensity (with livestock)	Areas where the natural vegetation has been altered by drainage, irrigation, etc., for the grazing of domestic animals with a density of more than 1.2 animals/ha.
Citrus	Areas devoted to the production of oranges and citrus in general.
Row crops	Areas devoted to the production of all types of vegetables usually grown in rows, whether producing or not.
General agriculture	Applies to type of crop not known or crops other than citrus or row crops.
Agriculture–high-intensity	Dairy farms and large-scale cattle feed lots, chicken farms, and hog farms.
Recreational/open land–low-intensity	Areas of natural vegetation in cities maintained as nature parks, and undeveloped land that may be occupied by natural vegetation in an agricultural or urban landscape. Also includes access roads within conservation/protected lands.
Recreational/open space–medium-intensity	Areas with grassy lawns in urban landscape including recreational land such as playgrounds, ball fields, and swimming beaches. Also applies to land that has been cleared and prepared for construction, dirt roads, barren land, and open areas surrounding power lines. Includes human-created water bodies (retention ponds, canals, reservoirs, etc).
Recreational/open land–high-intensity	Applies to stadiums not associated with institutions such as schools and universities, golf courses, and racetracks (horse, dog, car).
Single family residential–low-density	Areas that are predominantly residential units with a density less than 10 units/ha.
Single family residential–medium-density	Areas that are predominantly residential units with a density between 10 and 20 units/ha.
Single family residential–high-density	Areas that are predominantly residential units with a density of more than 20 units/ha.
Multi-family residential–low-intensity	Areas that are predominantly multi-family residential units such as condominiums and apartment buildings up to 2 stories.

(*Continued on next page*)

Table 1. Land Uses and Definitions, Cont'd

Land use / land cover	Definition
Multi-family residential–high-intensity	Areas that are predominantly multi-family residential units such as condominiums and apartment buildings with 3 or more stories.
Commercial–low-intensity	Commercial strip.
Commercial–high-intensity	Commercial mall with associated storage buildings and parking lots, hotels, convention centers, and theme parks.
Institutional	Schools, universities, religious, military, medical and professional facilities, and government buildings.
Industrial	Land uses include manufacturing, assembly or processing of materials/products and associated buildings and grounds. Also includes extractive areas and mining operations, water supply plants, waste treatment facilities, and solid wastes disposal facilities.
Transportation–low-intensity	Paved road with 2 lanes (includes shoulders), railroads, and canals used for transportation.
Transportation–high-intensity	Paved road with more than 2 lanes (includes shoulders), airports, railroad terminals, bus and truck terminals, port facilities, and auto parking facilities when not directly related to other land use.
Central business district–low-intensity	Central business districts with an average of 2 stories.
Central business district–high-intensity	Central business districts with an average of more than 2 stories.

Note: Extracted from Brown, M. T. & , Vivas B. M. (2005)

3. Quantifying Human-Development Intensity By Land Use: Land uses within the "area of influence" are assigned an LDI coefficient (from 1-10) from Table 2 (extracted from the literature), and then an overall LDI ranking is calculated as an area weighted average.

   Using the GIS, total area and percent of total area occupied by each of the land uses is determined, and then the LDI calculated, as follows:

   $LDI_{total} = \sum \%LU_i \cdot LDI_i$

   Where:

   LDI_{total} = LDI ranking for landscape unit

   $\%LU_i$ = percent of the total area of influence in land use i

   LDI_i = landscape development intensity coefficient for land use i

Table 2. Land Use Classification, Nonrenewable Empower Density, and Resulting LDI Coefficients

Land use	Nonrenewable empower density (E14 sej/ha/yr)	Ln Nonrenewable empower density	LDI coefficients[a]
Natural system	0.00		1.00
Natural open water	0.00		1.00
Pine plantation	5.10	1.63	1.58
Recreational / open space – low-intensity	6.55	1.88	1.83
Woodland pasture (with livestock)	8.00	2.08	2.02
Improved pasture (without livestock)	17.20	2.84	2.77
Improved pasture – low-intensity (with livestock)	33.31	3.51	3.41
Citrus	44.00	3.78	3.68
Improved pasture – high-intensity (with livestock)	46.74	3.84	3.74
Row crops	107.13	4.67	4.54
Single family residential – low-density	1077.00	6.98	6.9
Recreational / open space – high-intensity	1230.00	7.11	6.92
Agriculture – high intensity	1349.20	7.21	7.00
Single family residential – medium density)	2175.00	7.68	7.47
Single family residential – high density	2371.80	7.77	7.55
Mobile home (medium density)	2748.00	7.92	7.70
Highway (2 lane)	3080.00	8.03	7.81
Low-intensity commercial	3758.00	8.23	8.00
Institutional	4042.20	8.30	8.07
Highway (4 lane)	5020.00	8.52	8.28
Mobile home (high density)	5087.00	8.53	8.29
Industrial	5210.60	8.56	8.32
Multi-family residential (low rise)	7391.50	8.91	8.66
High-intensity commercial	12 661.00	9.45	9.18
Multi-family residential (high rise)	12 825.00	9.46	9.19
Central business district (average 2 stories)	16 150.30	9.69	9.42
Central business district (average 4 stories)	29 401.30	10.29	10.00

[a]The LDI coefficient is calculated as the normalized (on a scale of 1.0 to 10.0) natural log of the empower densities.

Note: Extracted from Brown, M. T. & , Vivas B. M. (2005)

Development of the LDI

The metric used for quantifying human activity is empower density (emergy use per unit area per time measured in units of sej/ha yr−1).

Emergy is energy that has been corrected for different qualities, and its unit of measure is the solar emergy joule (abbreviated sej).

To derive solar emergy of a resource or commodity, it is necessary to trace back through all the resources and energy that are used to produce it, and express each in the amount of solar energy that went into its production. When expressed as a ratio of the total emergy used to the energy of the product, a transformation coefficient results (called transformity, whose dimensions are sej/J). As its name implies, the transformity can be used to "transform" a given energy into emergy, by multiplying the energy by the transformity. For convenience, in order not to have to calculate the emergy in resources and commodities every time a process is evaluated, previously calculated transformities are used.

Emergies used in calculating the LDI are all nonrenewable energies including electricity, fuels, fertilizers, pesticides, and water (both public water supply and irrigation).

Empower density is calculated as average values for land use categories.

Energy consumption data were collected from actual billing records and from the literature and averaged on a per unit area basis for different land use types.

When empower densities are calculated, the natural log of the empower densities are then calculated, and the resulting values normalized on a scale from 1 to 10, with the LDI coefficient for natural lands equal to 1.0 and a LDI coefficient of 10.0 for the highest intensity land use, the Central Business District.

Examples of Case Studies

Parker (in Brown *et al.*, 1998) calculated several different LDIs for 64 watersheds in the St. Marks River basin of the Florida Panhandle and related them to total phosphorus loading.

In recent studies of depressional wetlands in Florida, an LDI has been used to characterize the human disturbance gradient as a means of developing biological indicators for wetlands (Brown *et al*., 2001, 2003; Lane, 2003).

B. Summary of Calculation of Landscape Development Intensity (LDI) Values for Land Use Types in Arkansas and Florida: Lessons Learned by Benjamin Vivas (2007)

Vivas discusses how he calculates LDI for the Bayou Meto Watershed (BMW), located in eastern Arkansas, between the Arkansas River and the White River.

In this paper, Vivas notes that at this point, one can't conclude that the LDI values for different land uses from one geographical locations can be transferred to another location. Emergy evaluations for similar land uses in Arkansas and Florida showed mixed results; lower end and middle scale LDI values (natural and agricultural lands) showed similar results, while high end LDI values (urban lands) showed some variations. He mentions that dissimilarities may be attributed to differences between energy usage between geographic locations, how land uses were defined, or the number or type of inputs considered in the emergy evaluations for the same or similar land use type. Data from other locations are needed for further comparisons.

His abstract summarizes the lessons learned for calculations of LDI in the future.

> "Results from this work, and previous work done in Florida, have highlighted some lessons learned that can assist when calculating LDI values for land types in the future. First, the spatial resolution of the land use data sources need to be taken into account; as the scale becomes finer the number of land uses that can be identified tends to increase. Defining a set of functional LDI land use categories that appropriately describe the system under investigation is critical to optimize

resources. Second, since existing land use data were probably developed to respond to research needs other than emergy-based studies, adjustments to the data may be required to define functional LDI land use categories. Third, emergy evaluations for similar land uses in both states have shown mixed results, calling for further research to determine the transferability of areal non-renewable empower density values for land uses between different geographic locations."

It must be noted, that Vivas (2007) used different calculations for the LDI than Brown & Vivas (2005). Those changes made for the new calculations of the LDI are fully discussed in Brown & Reiss (2010).

C. Summary of Landscape Development Intensity and Pollutant Emergy/Empower Density Indices as Indicators of Ecosystem Health by Mark T. Brown and Kelly Chinners Reiss (2010)

This paper talks about the new calculation of LDI used by Vivas(2007). In this summary, the research team only highlights the differences in the new calculations.

A new method is proposed for calculating the LDI of a landscape unit based on a $\log_{10}$ scale of the ratio of the nonrenewable areal empower density of the landscape unit to an areal empower density of the environmental baseline of the landscape unit. The environmental baseline is the average renewable areal empower density.

In addition, Brown and Reiss propose a spatial averaged LDI for point source pollutants, especially those associated with pollutants such as nutrients, metals, and other toxins. In general, metals, nutrients, and toxins have high Unit Emergy Values (UEVs) and as a result, when excess concentrations occur, they are capable of instigating significant changes in ecosystem processes, which often result in declines in ecosystem health.

Table 3. Types of Measurements Used for the LDI

Name	Definition	Unit of measure	Unit of measure abbreviated	Symbol
Emergy	the amount of energy of one type (usually solar) that is directly or indirectly required to provide a given flow or storage of energy or matter.	Emojoules (solar emojoules)	J (seJ)	ε
Empower	Emergy per unit time	emjoules per time	seJ/time	ω
Transformity (transformity of solar radiation is assumed to be 1 (1.0 seJ/J)	The resulting ration when the emergy required to make something is expressed as a ratio to the available energy of the product	solar emergy joules per joule of output flow.	seJ/J	τ
Specific* emergy	the unit emergy value of matter defined as the emergy per mass	solar emergy per gram.	seJ/g	σ
areal empower intensity	emergy per unit time per unit area/ empower per area		energy*time^{-1} *area^{-1}	$\alpha\omega\tau$
emergy denSity	The concentrations of pollutants in the environment, especially in aqueous environments.	emergy per unit volume	eJ/volume	$\varepsilon\delta$

*Solids maybe evaluated best with data on emergy per unit mass for its concentration.

Because energy is required to concentrate materials, the unit emergy value of any substance increases with concentration. Elements and compounds not abundant in nature therefore have higher emergy/mass ratios when found in concentrated form since more work was required to concentrate them, both spatially and chemically.

Why the LDI was Redefined

LDIs for larger areas calculated in this manner involved the averaging of logs (since individual land use LDIs are natural logs of their areal empower intensity). This method of calculating average LDIs for landscape areas composed of several land use types inserted significant bias in favor of the land uses with lower areal empower intensity. Further, it was apparent that impact of human disturbance intensity should in some way be related to the background renewable areal empower intensity of the landscape. That is to say, the effect of the nonrenewable emergy intensity is proportionally smaller if the background renewable emergy intensity is greater. This led to redefining the LDI in relation to the renewable background areal empower intensity. Finally, a limitation resulted from defining strict classes of land use types and limiting the calculation of LDIs to known land uses and their areal empower intensity. By redefining the LDI based on the nonrenewable empower intensity of land uses rather than a predetermined LDI for each land use, more flexibility in application of the method may result (see Table 4).

New Calculation for the LDI

1. Areas of each land use type within the landscape unit are summed and expressed as percent of total area.
2. Percent of land use types are multiplied by the nonrenewable areal empower intensity of each type and summed.
3. The following equations are applied :

   LDI = 10 * log ($\alpha\omega\tau_{\text{Total}}$ /$\alpha\omega\tau_{Ref}$)

   Where:
   LDI = Landscape Development Intensity index for a given landscape unit;
   $\alpha\omega\tau_{\text{Total}}$ = Total areal empower density (sum of renewable background areal

empower intensity and nonrenewable areal empower density of land uses)
$\alpha\omega\tau_{Ref}$ = Renewable areal empower intensity of the background environment.

The total areal empower intensity ($\alpha\omega\tau_{\text{Total}}$) is calculated as follows:

$$\alpha\omega\tau_{\text{Total}} = \alpha\omega\tau_{Ref} + \sum(\%LU_i * \alpha\omega\tau_i)$$

Where
$\%LU_i$ = Percent of the total area in land use i
$\alpha\omega\tau_i$ = The nonrenewable empower intensity for land use i.

4. The LDI is calculated for the entire area of interest, without averaging logs, but instead calculating the weighted average nonrenewable areal empower intensity.

Table 4. Landscape Development Intensity (LDI) Coefficients of Typical Land Uses

Notes	Land Use	Nonrenewable Areal Empower Intensity (E15 sej $^{-1}$ ha $^{-1}$ yr $^{-1}$)	LDI_{n} [a]
1	Natural land/open water	0.0	0.00
2	Pine plantation	0.5	1.00
3	Low intensity open space/recreational	0.5	1.02
4	Unimproved pastureland (with livestock)	0.5	1.04
5	Improved pasture (no livestock)	2.0	3.07
6	Low intensity pasture (with livestock)	3.4	4.34
7	High intensity pasture (with livestock)	5.9	6.03
8	Medium intensity open space/recreational	6.1	6.10
9	Citrus	7.8	6.94
10	General agriculture	15.1	9.38
11	Row crops	20.3	10.53
12	High intensity agriculture (dairy farm)	50.4	14.25
13	Recreational/open space (high intensity)	123.0	18.02
14	Single-family residential (low density)	197.5	20.05
15	Transportation—2-lane highway	308.0	21.97
16	Single-family residential (med. density)	658.3	25.25
17	Single-family residential (high density)	921.7	26.71
18	Transportation—4-lane highway, low intensity	2533.7	31.10
19	Multifamily residential (low density)	4213.3	33.30
20	Institutional	4042.2	33.12
21	Transportation—4-lane highway, high intensity	5020.0	34.06
22	Low intensity commercial (comm. strip)	5173.4	34.19
23	Industrial	5210.6	34.23
24	High intensity commercial (mall)	8372.4	36.28
25	Multifamily residential (high rise)	12771.7	38.12

(continued)

Table 4. Landscape Development Intensity (LDI) Coefficients of Typical Land Uses, Cont.

Notes	Land Use	Nonrenewable Areal Empower Intensity (E15 seJ $^{-1}$ * ha $^{-1}$ * yr $^{-1}$)	LDI_{R}*
26	Central business district (avg. 2 stories)	16150.3	39.14
27	Central business district (avg. 4 stories)	29401.3	41.74

* $LDI = 10 * \log[(\alpha\varpi\iota_i + \alpha\varpi\iota_{ref}) / \alpha\varpi\iota_{ref}]$
where
$\alpha\varpi\iota_i$ = nonrenewable areal empower density of Land Use *i*
$\alpha\varpi\iota_{ref}$ = areal empower density of background environment;
Florida = 1.97E+15 seJ $^{-1}$ * ha $^{-1}$ * yr $^{-1}$

Notes:

1. Nonrenewable empower density for natural systems = 0.
2. Doherty (1995).
3. Average of empower densities of 2 and 4.
4. Based on 0.09 cows/ha/yr (27 acres/animal) (Kalmbacher and Ezenwa 2006). Empower density to support 0.09 cows: 0.53 E15 sej/ha/yr (Brandt-Williams 2002).
5. Brandt-Williams (2002).
6. Based on 0.57 steer/ha/yr (1.76 ha/animal) (Arthington et al. 2007). Empower density to support 0.57 steer: 3.38 E15 sej/ha/yr = Improved Pasture (5) + 1.61 E15 sej/ha/yr
7. Based on 2 steer/ha/yr (Brandt-Williams 2002). Empower density to support two steer: 5.93 E15 sej/ha/yr
8. Assume three times intensity of improved pasture. In an urban landscape applies generally to grassy lawns (Falk 1976).
9. Brandt-Williams (2002).
10. Average of all crops (Brandt-Williams 2002).
11. Average of empower densities for 6 row crops (Brandt-Williams 2002).
12. Brandt-Williams (2002).
13. Based on the emergy evaluation for a golf course (Behrend 2000).
14. Parker (1998) and Brown (1980). Assumes 1.5 units per hectare.
15. Parker (1998).
16. Parker (1998) and Brown (1980). Assumes 5 units per hectare.
17. Based on Brown (1980). Assumes 7 units per hectare.
18. Brown and Vivas (2005).
19. Parker (1998) and Brown (1980). Assumes 32 units per hectare.
20. Brown (1980).
21. Vivas and Brown (2007).
22. Vivas and Brown (2007).
23. Parker (1998) and Brown (1980).
24. Vivas and Brown (2007).
25. Parker (1998) and Brown (1980). Assumes 97 units per hectare.
26. Brown (1980).
27. Brown (1980).

Note: Extracted from Brown, M. T. & , Reiss K. C. (2010)

The Pollutant Density Index (PDI)

This paper also discusses the Pollutant Density Index (PDI).

What is the PDI?

The Pollution Density Index is an index that relates the intensity of pollutants to the average intensity of the reference environment.

Why are we Interested in the PDI?

Although the LDI measures the impacts of general development intensity on ecological systems, it does not capture the production or subsequent concentration of a pollutant. This needs to be recognized as pollutants have deleterious effects that extend beyond their initial source of introduction into the environment. The PDI is designed to account for those deleterious effects.

PDI’s Method

PDI explains the impact of pollutants by measuring the pollutants’ emergy and empower density relative to the background environments.

Calculations for the PDI are as follows:

$PDI = 10*\log(\varepsilon\delta_{Total}/\varepsilon\delta_{Ref})$

Where:

PDI = Pollutant Density Index for a given environmental volume

$\varepsilon\delta_{Total}$ = Total emergy density of the volume (sum of reference emergy density and pollutant emergy density [$\varepsilon\delta$])

$\varepsilon\delta_{Ref}$ = Emergy density of the background environment (freshwater = 1.45 E8 seJ/L)

The total emergy density ($\varepsilon\delta_{Total}$) is calculated as follows:

$\varepsilon\delta_{Total} = \varepsilon\delta_{Ref} + \sum\varepsilon\delta_i$

Table 5. Unit Emergy Values (UEVs) of Selected Metals, Nutrients, and Pesticides

Item	Specific Emergy (seJ/g)	Source
Elements		
Silicon	5.07E+08	See Appendix 8.1
Aluminum	1.74E+09	"
Iron	2.78E+09	"
Calcium	3.84E+09	"
Sodium	5.10E+09	"
Potassium	5.44E+09	"
Magnesium	6.75E+09	"
Titanium	2.26E+10	"
Hydrogen	1.00E+11	"
Phosphorus	1.08E+11	"
Carbon	1.49E+11	"
Manganese	1.56E+11	"
Sulfur	2.70E+11	"
Barium	2.81E+11	"
Chlorine	3.12E+11	"
Chromium	4.01E+11	"
Fluorine	4.84E+11	"
Zirconium	5.61E+11	"
Nickel	7.39E+11	"
Copper	2.06E+12	"
Nitrogen	7.02E+12	"
Lead	1.40E+13	"
Arsenic	6.68E+13	"
Uranium	7.80E+13	"
Cadmium	9.36E+14	"
Silver	1.75E+15	"
Mercury	2.09E+15	"
Gold	4.53E+16	"
Pesticides		
Herbicides	1.7E+10	From Pimentel (1980)
Insecticides	2.7E+10	From Pimentel (1980)

Note: Extracted from Brown, M. T. & , Reiss K. C. (2010)

Interpretation of the PDI

Table 6. US EPA Quality Criteria, Resulting Emergy Density, and Calculated PDI

Parameter	Units	Acute[a]	Chronic[a]	EPA Recommended[b]	Emergy Density[c] (seJ/L)	PDI[d]
Aluminum	μg/L	750	87		1.31E+06	0.09
Chromium	μg/L	16	11		6.42E+06	0.42
Copper	μg/L	13	9		2.68E+07	1.64
Lead	μg/L	65	2.5		9.10E+08	19.55
Arsenic	μg/L	340	150		2.27E+10	50.27
Cadmium	μg/L	2	0.25		1.87E+09	26.01
Mercury	μg/L	1.4	0.77		2.93E+09	30.21
Pesticide (Chlordane)	μg/L	2.4	0.0043		6.48E+04	0.00
Phosphorus (total)	μg/L			10	1.50E+05	0.01
Nitrogen (total)	mg/L			0.52	8.32E+06	0.54

[a] From the US EPA National Recommended Water Quality Criteria from May 2005. http://www.epa.gov/waterscience/criteria/wqcriteria.html
[b] EPA document EPA-822-B-00-013 from December 2000. http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/lakes/
[c] Calculated as the product of UEV in Table 8.2 and acute quantity of constituent.
[d] PDI = 10 * log ($\varepsilon\delta_{Total}$ / $\varepsilon\delta_{Ref}$) where $\varepsilon\delta_{Ref}$ = 1.45 E8 seJ/L for freshwater (Odum et al. 2000).

Note: Extracted from Brown, M. T. & , Reiss K. C. (2010)

"Where emergy density is significantly higher than the average of the ecosystem components it is released into, one might expect significant changes in ecosystem functions" (p.180).

What is PED?

The Pollutant Empower Index is an index that measures the impact of known discharges of pollutants in aquatic systems by calculating the flux of the pollutant and the productivity of the background environment (measured as empower of the environment).

PED's Method

PED = 10* log($\phi\delta_{Total}$/$\phi\delta_{Ref}$)

Where: PED = Pollutant Empower Density Index for a given landscape unit

$\phi\delta_{Total}$ = Total empower density (sum of background empower density and pollutant empower density)

$\phi\delta_{Ref}$ = Empower density on the background environment

The total empower density ($\phi\delta_{Total}$) is calculated as follows:

$\phi\delta_{Total} = \phi\delta_{Ref} + \sum\phi\delta_i$

Where:

$\phi\delta_i$ = Empower density of pollutant i

Table 7. Empower Density of Aquatic Ecosystems

Ecosystem	Empower Intensity ($seJ*m^{2*}yr^{-1}$)	Empower Density ($seJ*m^{3*}yr^{-1}$)	Source
Freshwater systems			
Subtropical spring	3.80E+11	1.90E+11	Collins and Odum 2000
Subtropical lake	9.40E+11	4.09E+11	Brown and Bardi 2001
Subtropical herb. wetland	3.69E+11	5.59E+11	Bardi and Brown 2000
Subtropical eutrophic lake	3.30E+12	2.75E+12	Brown and Bardi 2001
Saltwater systems			
Louisiana estuarine sys.	9.60E+09	9.60E+09	Odum and Collins 2002
Oyster reef	7.57E+09	1.51E+10	Odum and Collins 2002
Coral reef	2.60E+11	1.73E+11	McClanahan 1990

Note: Extracted from Brown, M. T. & , Reiss K. C. (2010)

III. Integrated Valuation of Ecosystem Services and Tradeoffs (INVEST)

Description

InVEST consists of 18 different models for mapping and valuing ecosystem services at global, regional, and local scales by using production functions to define how changes in the ecosystem's structure and function will likely affect the flows and values of ecosystem services. A user can choose to model only the ecosystems of interest using maps as information sources for input data. The models can be run independently or as a script tools in the ArcGIS Toolbox environment, but requires mapping software such as QGIS or ArcGIS, to view the results as InVEST produces maps as outputs (NatCap, n.d.).

Brief History and Availability

InVEST is a suite of models developed by NatCap, a partnership of Stanford University, the University of Minnesota, the Nature Conservancy and World Wildlife Fund. That means that NatCap is a team of academics, software engineers and real world professionals (NatCap, n.d.) . InVEST is a free or open source software that can be downloaded at : http://www.naturalcapitalproject.org/invest/ .

Ecosystem Services Modelling

InVEST includes assessments of aesthetic quality, carbon storage and sequestration, coastal protection, coastal vulnerability, crop pollination, habitat risk assessment, managed timber production, marine fish aquaculture , marine water quality, offshore wind energy, overlap analysis model, recreation, reservoir hydropower production, sediment retention (avoided dredging and water quality regulation), terrestrial biodiversity (habitat quality and rarity), water purification (nutrient retention) and wave energy (NatCap, n.d.).

Strengths and Challenges (Förster)

Table 8: Strengths and Challenges of InVEST

Strengths	**Weaknesses**
Analysis of multiple services allows for trade-off analysis. Spatially explicit (maps) allowing for analysis at local, regional, global scale. Tiered design allows the use of simple to more complex models based on availability of data and expertise. InVEST is open source and available for free. Documentation and guidance are available.	Quality and availability of input data can be an issue and can influence the quality of results. Experience and expertise in using InVEST can influence the credibility of results. Processing and interpreting results can be difficult for beginning users. Some models may be oversimplified for a particular purpose. In this case it is recommended people use alternative ecosystem service models such as SWAT in combination with InVEST.

Training

Naturalcapitalproject.org contains a detailed user's guide with useful descriptions and pictures that will train users. The guide provides the following applicable information for each model: summary, introduction, technical explanation of the model, limitations and simplifications, data needs, instructions to run the model and interpret the results, and references.

Natural capital project also provide on-line courses, webinars, regional workshops, and a "training track" at the Natural Capital Symposium. There is also a project-specific support in which NatCap experts work with you in an on-site seminar or small-group session to generate results using your own data.

Additionally, the website contains a forum for users to interact, a link to free online course and a library with documentation about testing, validation, and application of InVEST (NatCap, n.d.).

Data/Input Requirements

The InVEST User Guide documents, in detail, each model, and the necessary inputs in addition to other documentation about the models. This section provides a summary of data needs/inputs gathered from the user guide (Sharp, 2015).

1. **Habitat Quality Model**

The habitat quality model requires the following data: land use/land cover (LULC) (map); threat impact distance by threat type(table); threat impact weights by threat type (table); form of decay function by threat type(table); threat maps; habitat preference by species group (table); habitat sensitivity to threats (table); and half saturation constant (table). The following data is optional for the habitat quality model: protected status.

2. **Carbon Model**

The carbon model requires the following data: Land use/land cover (LULC) (map); carbon in aboveground biomass (table); carbon in belowground biomass (table); carbon in dead organic matter (table); and carbon in soil (table).

The following data is optional: carbon removed via timber harvest; first year of timber harvest; harvest frequency; half life of harvested wood products; carbon density in harvested wood; and biomass conversion expansion factor; future land use/land cover.

The following data is optional for valuation: value of sequestered carbon; discount rate; timespan; and annual rate of change in price of carbon.

3. **Pollination Model**

The pollination model requires the following data: land use/land cover (LULC) (map); pollinator species, nesting and foraging season (table); nesting and foraging availability by

LULC (tables); half saturation constant (for pollination) (point value); and proportion of total yield due to wild pollinators (dependence on pollination) (point value for each crop).

4. **Annual Water Yield (Hydropower)**

The hydropower model requires the following data: land use/land cover (LULC) (map); annual average precipitation (map); annual average reference evapotranspiration (map); plant available water content (map); etk/crop coefficient by LULC (table); root depth by LULC (table); effective soil depth (map); zhang coefficient; consumptive use by LULC (table); watersheds above points of interest (shapefile); and subwatersheds above points of interest (shapefile).

The following data is optional for valuation: discount rate; timespan; calibration coefficient; turbine efficiency; reservoir fraction for hydropower; average annual head; hydropower production costs; and hydropower price.

5. **Nutrient Retention (Water Purification)**

The water purification model requires the following data: Land use/land cover (LULC) (map); DEM (topography) (map); annual average precipitation (map); annual average reference evapotranspiration (map); plant available water content (map); etk/crop coefficient (by LULC) (table); root depth (by LULC) (table); effective soil depth(map); zhang coefficient; consumptive use (by LULC) (table); watersheds above points of interest (shapefile); subwatersheds above points of interest (shapefile); water yield (map) ; nutrient export/load coefficient (by LULC) (table); nutrient filtration efficiency (table); threshold flow accumulation; and allowed level of nutrient pollution by watershed (table).

The following data is optional for valuation: discount rate; timespan; and annual average nutrient removal costs.

6. **Sediment Retention (Erosion Control)**

The sediment retention model requires the following data: land use/land cover (LULC) (map); DEM (topography) (map); annual average precipitation (map); watersheds above points of interest (shapefile); subwatersheds above points of interest (shapefile); threshold flow accumulation; rainfall erosivity (map); soil erodibility (map); management factor

USLE (by LULC) (table); crop factor USLE (by LULC) (table); sediment retention efficiency (table); slope threshold; reservoir dead volume (reservoir points of interest, by watershed) (table); and allowed sediments load in rivers (TMDL, etc., by watershed) .

The following data is optional for valuation: discount rate; timespan; and annual average sediment removal costs; and annual average dredge cost.

7. Coastal Vulnerability Model

The coastal vulnerability model uses geo-physical, population, habitat, wind, sea level change, and surge potential data.

8. Coastal Blue Carbon Model

The coastal blue carbon model requires biophysical inputs and economic inputs.

The biophysical inputs include land use/land cover (LULC) maps; years of provided LULC maps; carbon pool initial values by LULC class; Transition matrix; carbon pool transient values by LULC class.

The economic inputs include value of sequestered to ton on carbon, and the discount rate.

9. Fisheries Model

The data available for specific fisheries may vary substantially. As a result of this the model is designed to provide the use with flexibility in terms of the data used to estimate inputs for the model parameters. Data that can be used by the model include species' length, weight, maturity, or fecundity at a given age/stage are important for specifying how the population reproduces; historical data on prices can be used to estimate the value of harvests; or survival rates may be estimated from data or taken from literature values.

10. Habitat Risk Assessment Model

The habitat risk assessment model uses a tool that preprocesses the data so that all applicable criteria information is concatenated and rated. The required input for this tool include named habitat or species shapefile layers that will be included in the model; stressor layers; criteria information to determine how user ratings are input into the habitat risk assessment model. A default criteria based on peer-reviewed literature is provided. However, users can add or remove criteria if the default criteria are not applicable to the system being modeled. Optional input for the preprocessor are spatial criteria which are vector layer files, which would provide more explicit detail for a specific criteria in the assessment. Each feature in the shapefiles used MUST include a 'Rating' attribute which maps to a float or integer value desired for use as the rating value of that spatial criteria area. The preprocessor will output a ratings file (in csv format) for each habitat and an additional file for stressor buffers. Habitat CSVs will contain not only habitat-specific criteria information, but also all criteria that impact the overlap between that habitat and all applicable stressors. The stressor buffer CSV will be a single file containing the desired buffer for all stressors included in the assessment.

After the data is preprocessed, the input needed to run the risk assessment model include all the output files from the preprocessor; resolution of analysis; risk equation; decay equation; maximum criteria score; maximum criteria score; maximum overlapping stressors and sub region shapefiles.

11. Managed Timber Production Model

The managed timber production requires the following data: timber parcels, production table and market discount rate.

12. Marine Fish Aquaculture Production Model

The input required for this model include a GIS polygon/point dataset that contains fish farm location information and a numerical identifier for each farm; fish growth parameters; daily water temperature at farm tables; and farm operations table

The option inputs include uncertainty analysis data, and valuation parameters valuation analysis.

13. Nearshore Waves and Erosion Model/Wave Attenuation & Erosion Reduction: Coastal Protection

The erosion protection model is made up of two primary sub-models: the profile generator; and the nearshore waves and erosion models. It is recommended to first utilize the profile generator tool to obtain a cross-shore profile that contains bathymetry and backshore information. This tool will also help you obtain several pieces of useful information including: the bathymetry and nearshore topography along the profile of interest; the type of natural habitats present at the site, as well as your location along the profile; values for offshore wave height and wind speed and fetch direction for the site. Once this profile information has been obtained and forcing parameters have been selected, the nearshore waves and erosion model can be run.

The required inputs for the profile generator include a land point shapefile; land polygon; a cross-shore profile or a bathymetric grid, land point buffer distance and length of your profile; smoothing percentage; erosion protection excel table; wave watch III model data and wave watch III search distance.

The actual and the nearshore waves and erosion model include erosion protection table, cross-shore wave profile; wave heights; wave period; wind speed in meters per second; fetch distance in meters; water depth in meters; storm duration in hours; surge elevation in meters; modal spatial resolution; longshore extent in meters; property value; return period of the storm in years; discount rate; time horizon of valuation in years.

14. Marine Water Quality Model

The inputs for the marine water quality model include an area of interest shapefile; a land polygon, output pixel size in meters; grill cell depth; source point centroids; source point loading table; decay coefficient; dispersion coefficients and advection vectors (UV as point data) which is optional.

15. Unobstructed Views: Scenic Quality Provision

The required inputs for the scenic quality provision include an area of interest shapefile; features impacting scenic quality; a digital elevation model; a refractivity coefficient; and a population raster.

The optional inputs for the scenic quality provision include the cell size in meters, and overlap analysis features.

16. Visitation: Recreation and Tourism

The required inputs for the recreation and tourism model include an area of interest shapefile; and start year and end year.

The optional inputs for the recreation and tourism model include a predictor table to compute a regression; and a scenario predictor table.

17. Wave Energy Production

The required inputs for the wave energy production model include an area of interest shapefile; a machine performance table; and a global digital elevation model.

The optional inputs include grid connection points, machine economic table and the number of machine units for economic valuation.

18. Offshore Wind Energy Production

The required inputs for the offshore wind energy production include wind data points; bathymetric DEM; land polygon for distance calculation; global wind energy parameters; turbine type; number of turbines; minimum and maximum depth for offshore wind farm installation; minimum and maximum distance for offshore wind farm installation; cost of foundation type; discount rate; grid connection points; average shore to grid distance; use price table; wind energy price table; price of energy per kilowatt hour; and annual rate of change in the price of wind energy.

IV. Other Land Use Simulation Models

This section discusses other land use models that may be applicable to the Pellicer Watershed.

A. Land Simulation Models with Economic Valuation

1. Multiscale Integrated Models of Ecosystem Services (MIMES)

MIMES is an integrated set of models for land use change and marine spatial planning. The models quantify the effects of land and sea use change on ecosystem services. The models can be run at global, regional, and local scale. MIMES consists of different economic and ecological models that are interconnected in order to simulate ecosystems and socio-economic systems in space and over time as well as the interactions between them. MIMES incorporates stakeholder input and biophysical data from GIS sources, time series, etc. to simulate ecosystem and economic components under different scenarios. Stakeholders define the demand for ecosystem services in an adaptive process of programming. With MIMES, all ecosystem services can be modeled, provided that ecological and socio-economic data are available. The simulations are used to obtain insights on how development, management and land/marine use decisions affect natural, human and built capital and corresponding ecosystem services.

MIMES is able to provide models with four different tiers of output:

1) Tier 1 provides ecosystem service valuation (ESV) using GIS data and benefit transfer used for economic valuation, within a spatial approach.
2) Tier 2 provides land use change simulations and ESV. This is very similar to Tier 1, but time series are used as an input to model temporal dynamics.
3) Tier 3 provides land use change and ecosystem production function and ESV. This tier uses GIS data as input and also biophysical models to calculate dynamic series. Additionally, a marginal price approach is used instead of benefit transfer for a space and time specific model of probability.

4) Tier 4 is still in progress. It uses GIS data, biophysical models and input- output economic models for a complete green accounting (Schmidt).

MIMES website:

http://www.afordablefutures.com.

Background and Availability

MIMES was developed by Dr. Roelof Boumans, the Director of AFORDable Futures LLC. Although MIMES is free, MIMES currently uses Simile programming interface, which requires the purchase of a site license. Information and documentation is available by contacting the Tulalip Tribes, or Roelof M. Boumans or sending an email to *info@afordablefutures.com*, as a readily available download link was not found http://www.afordablefutures.com (Office of Science and Technology Policy, Council on Environmental Quality, 2015).

Training

A link to a webinar is available on the website for AFORDable Future's website. The webinar provides an example of the software's capabilities. However, this is not sufficient information for someone else to be able to use the program (AFORDable Futures, n.d.).

AFORDable Future's website discusses a MIMES Intro folder that can be made available from them. The Intro Folder contains the following information:

1) general background on modeling and specific background on MIMES
2) recorded history of collaboration with AFORDable Futures
3) discussion of software needs and outline of infrastructure growing up around MIMES
4) concepts and tutorials selected to help identify the range of performance needed from the model
5) conceptual schematics organizing economic sectors and environmental factors specific to the location being studied
6) existing examples of working models

7) modification of data and other parameters that provide a chance to "play" with an existing model
8) a list of issues reflected in previous scenarios and a background article linking simulation games and learning
9) parameters emerging from discussions to identify issues and time frame in the location of interest. This is where the "what if" questions are formulated and model inputs determined to give a simulated experience that is informative.
10) maintaining final documents that are generated by the user, in collaboration with AFORDable Futures. This includes contracts and other working agreements as well as model outputs and commentaries (AFORDable Futures).

About three months is required to learn the model functionally and run the model. Additionally, the expertise necessary includes: 1) knowledge about programming with Simile programming interface, 2) identifying indicators and data for the model input, 3) knowledge of biophysical and socio-economic interdependence, and; 4) expertise with stakeholder engagement to adjust the qualitative settings of the MIMES models (Schmidt).

Data Needs

The About ValuES database profile sheet for MIMES states that the model needs biophysical data from GIS sources and time series to run (Schmidt). A detailed list data needs is not provided but rather the user needs to be familiar with data acquisition and management for the biophysical and socio-economic processes that he/she would be interested in modeling.

Strengths and Challenges (Schmidt)

Table 9. Strengths and Challenges of MIMES

Strengths	Challenges
MIMES is a highly integrative, interdisciplinary software that is able to incorporate various types of data (demographics, biophysical, economics) MIMES builds on stakeholder input for specifying scenarios, information needs and also for model specification MIMES is a dynamic and spatial model that is flexible and adaptable to specific case studies MIMES has a tiered approach that allows it to deal with data availability and the state of system knowledge MIMES can perform spatially explicit trade-off analysis, provided that data is available MIMES can be run at multiple scales (geographical and temporal)	MIMES needs a lot of data input. Data gathering and adjustment of data is time consuming. MIMES has variability in the definition of inter-linkages between variables in the model. As a result of this, there can be inconsistency and varying uncertainties between different MIMES models and case studies Adjusting any settings in the model, requires intimate knowledge of the model. Benefit transfer method for producing value data bears considerable uncertainties

2. Artificial Intelligence for Ecosystem Services (ARIES)

ARIES is a web application developed to assess the ecosystem services and measure their values to humans in order to make environmental decision-making more effective.

ARIES consists of different models and datasets which are used to estimate supply, demand, and distribution among beneficiaries. The modules can be customized to user-specific applications. ARIES' features include modelled ecosystem service flows between source and use location, modelled distribution of beneficiaries, and comparison of potential and actual use, thus enabling efficiency estimates. Modelling framework and modules are adapted to biophysical and socio-economic conditions for the area being researched. (Schmidt, Values Method Profile - ARIES).

ARIES is made up of two types of interfaces: 1) the k.LAB software package for ARIES modelers, and; 2) k.EXPLORER or ARIES Explorer for end users. Developers aimed to make the software as 'user-friendly' as possible through intuitive GUI- and web-based interfaces (University of Vermont, Earth Economics, Conservation International).

As a network collaboration, ARIES scientists are developing protocols to share data and models in a cloud-based environment. This approach enables continual re-use and expansion of scientific data and models. As one progresses into an age of "big data," one can better leverage the power of new datasets, forging an international network of scientific collaborators capable of using Earth observation data to understand past environmental and social trends and predict how today's decisions will impact tomorrow's society.

ARIES can be used for spatial mapping and quantification of ecosystem services, spatial economic valuation of ecosystem services, natural capital accounting, optimization of payment schemes for ecosystem services (PES), conservation planning, spatial policy planning, and forecasting of change in ES provision (University of Vermont, Earth Economics, Conservation International).

ARIES' website:

http://aries.integratedmodelling.org/

Background and Availability

The ARIES project started in April 2007 with funding from the National Science Foundation to the Ecoinformatics Collaboratory at the University of Vermont, joined by Earth Economics and Conservation International. Partners from Madagascar, Puget Sound, and Veracruz, Mexico provided the initial case studies, data and knowledge to inform the emerging ARIES platform. Demonstration, proof-of-concept, and test releases were made available starting in 2008. A fully functional portal (ariesonline.org) including a prototype web tool was available to the public by 2012. Eight ecosystem service modules were originally developed by the ARIES team: Carbon sequestration and storage, Flood regulation, Coastal flood regulation, Aesthetic views and open space proximity, Freshwater supply, Sediment regulation, Subsistence fisheries and Recreation (University of Vermonth, Earth Economics, Conservation International, n.d.).

Full instructions to access the software is available on the "How To Use" page of ARIES' website. However, the software can be downloaded from www.integratedmodelling.org/collaboration (University of Vermont, Earth Economics Conservation International)

Training

Training is available through an annual two-week long event called the International Spring University on Ecosystem Services Modelling. Additionally, there are other events around that world that are given as the opportunity arises. Also, given that the ARIES explorer will be available in 2017; shorter workshops for intermediate to non-technical users will be done. An email has to be sent to team@integratedmodelling.org to learn about these opportunities or request customized training (University of Vermont, Earth Economics, Conservation International , n.d.).

Data Needs

The ARIES GeoServer currently stores several hundred spatial datasets that can be incorporated into ecosystem service models from global to local scales (Schmidt, Values Method Profile ARIES, n.d.).

Strengths and Challenges (Schmidt, Values Method Profile ARIES, n.d.):

Table 10. Strengths and Challenges of ARIES

Strengths	**Challenges**
ARIES' provides quantitative, spatially explicit modeling of supply, demand and flows from beneficiaries perspectives. ARIES computes potential and actual supply and demand as well as ecosystem services flows. Therefore, efficiency of use can be estimated by balancing supply and demand. ARIES considers data-related uncertainties based on probabilistic uncertainty analysis throughout all processes of ecosystem services supply and demand modeling, in order to enable accuracy assessment of results. Modelling framework of the ecosystem services-type modules is fully customizable to address biophysical and socio-economic conditions of individually defined research area, i.e. parameter and models can be user adjusted. Depending on the services and region of analysis, new data input requirements may be minimal, since the ARIES GeoServer stores several hundred spatial datasets that can be incorporated into ecosystem service models at global through local scales. Supports dynamic and spatial analysis of trade-offs	ARIES requires high proficiency in modeling is necessary to adapt already existing models to a new research area. ARIES requires high time and resource requirements for creating new models for case studies.

3. **Costing Nature**

Costing Nature assesses the effects of human interventions on ecosystem services at both the regional and local level. It can be used to obtain information for assessing consequences of a project or policy before its implementation. Costing Nature is a rule-based spatial model with a global dataset at 1-square km or 1-hectare resolution. The software incorporates spatial models for biophysical and socio-economic processes along with scenarios for climate, land use and economic change. Costing Nature calculates a baseline for current ecosystem services provision and combines them with an analysis of current pressure, future threats, biodiversity and conservation priority to produce an assessment of priority areas for conservation management on the basis of all of these factors (Muller, n.d.). Costing Nature focuses on providing the opportunity cost of nature being protected (to produce the ecosystems services that we need and value) versus obtaining the value that someone is willing to pay for it (King's College, AmbioTek).

Costing Nature's Website:

http://www.policysupport.org/costingnature

Background and Availability

Costing nature is part of a suite of web-based policy support systems developed, since 2003. Costing Nature was developed by King's College London, AmbioTEK CIC and United Nations Environment Program – World Conservations Monitoring Center. (UNEP_WCMC) (King's College, AmbioTek, n.d.).

The instructions to download Costing Nature are available at the following link: http://www.policysupport.org/costingnature.

Training

Training material is available at http://www.policysupport.org/training-course-schedule . This includes self-paced online training courses, model and data documentation, system (interface and functionality) documentation, a presentation on the science behind the PSS and a PowerPoint demo of the system functionality. Assistance can also be requested for you to train someone to use Costing Nature (King's College, n.d.) .

Data Needs

Global spatial data (GIS, remote sensing) at 1 square km or 1 ha resolution is provided by the tool. Users can also provide their own datasets (Ecosystems Knowledge Network , n.d.).

Strengths and Challenges (Muller, n.d.):

Table 11: Strengths and Challenges of Costing Nature

Strengths	**Challenges**
Costing nature provides comparisons between different scenarios' impacts on ecosystem services. The output can be visualized online or download as a GIS file that can be used for further analysis. Costing Nature has a large user community. Costing Nature is able to provide quantitative, spatially explicit analysis of environmental resources. With Costing Nature, users are able to verify output sensitivity to data uncertainties. The software is free for non-commercial use. Costing Nature is a rapid assessment method for institutions without GIS capacity. Costing Nature has a large pool of data available for use that can be used for applications anywhere globally at a range of different scales. The software is fast and easy to learn due to a straightforward user interface as well as detailed documentation about how to use the application. Skills requirements to use the software are low.	The user' own data sets must be formatted according to the application's requirements before uploading. It is necessary for the user to have some knowledge of environmental processes and GIS software. There is a limited range of services being modeled although more being added. Global data sets can be misleading when applied at local scale. Only land use and land cover change can be simulated; climate change impacts cannot be simulated. There are common limitations and data shortcomings associated with the program's statistical analysis as it does not predict outcomes, but gives a rough approximation of how ecosystem services delivery may change under various scenarios. The simulations are run on the provider's servers; users can only store a limited number of simulations at a time It is advised that users download their results in order to delete it on the server and start a new simulation.

4. MARXAN and MARXAN with Zones

Marxan, and Marxan with Zones, are a widely used spatial conservation planning software. It has been used for designing new reserve systems, multiple use zoning plans, or assessing the performance of existing reserve systems or plans. The method is applied in a flexible process and can incorporate stakeholder participation in various ways. It can use any thematic spatial data, which can be set as either threshold criteria (e.g. reach a target level) or as minimization criteria (e.g. for lowest cost). Outputs include spatial plans and cost information, and typically several scenarios are evaluated to illustrate trade-offs (Elizabeth Law, n.d.).

Marxan with Zones (called Marxan Z for short) is an extension of Marxan software. Marxan Z has the same functionality as Marxan but is able to allocate planning units to multiple zones (i.e. marine protected areas of various protection levels) and incorporate multiple costs into a systematic planning framework. The purpose of Marxan Z is to assign each planning unit in a study region to a particular zone in order to meet a number of ecological, social and economic objectives at a minimum total cost.

MARXAN's website:
http://www.uq.edu.au/marxan/

Background and Availability

Marxan is primarily a product of Ian Ball's PhD thesis that was supervised by and funded through Professor Hugh Possingham. In the initial stages, it was called SPEXAN (Spatially Explicit Annealing), and was funded by Environment Australia (EA). The Nature Conservancy (TNC) funded, through UC Santa Barbara, a project where Ian Ball integrated SPEXAN in to ARCVIEW. Then, Marxan's development was further funded by Great Barrier Reef Marine Planning Authority (GBRMPA) to meet the needs of their 2003-2004 rezoning plans (University of Queensland , n.d.).

Marxan Z was developed by Ian Ball and Hugh Possingham, from the Ecology Centre, University of Queensland with support from Ecotrust, whose interest in this software development arose from the need to support the design of marine protected areas along

California's coast as part of California's Marine Life Protection Act. There was also funding from the National Heritage Trust and the Applied Environment Decision Analysis centre plans (University of Queensland , n.d.).

MARXAN can be downloaded at:
http://www.uq.edu.au/marxan/index.html?page=77064&p=1.1.4 .

Training

On Marxan's website, there are Marxan User Manual, Marxan Z User Manual, Marxan Best Practices Guide, Marxan Email List, references, case studies, a draft tutorial and also course materials that were used in two-day courses at the University of Queensland in 2015 (University of Queensland , n.d.).

http://www.uq.edu.au/marxan/index.html?page=77652&p=1.1.3.3

Data Needs

MARXAN: Four input files are required. Marxan will not run without them. The required and optional files are summarized below.

Table 12. Marxan Input Files and Default Name(s)

Input File	**Default Name**	**Required**
Input Parameter File	input.dat	Yes
Conservation Feature File /Species File	spec.dat	Yes
Planning Unit File	pu.dat	Yes
Planning Unit Versus Conservation File Feature	puvspr2.dat	Yes
Boundary Length File	bound.dat	No
Block Definition File	blockdef.dat	No

The Input Parameter File is used to set values for all the main parameters that control the way Marxan works. It is also used to direct Marxan where to find the input files containing one's data and other variables, and where to place the output files.

The Conservation Feature File contains information about each of the conservation features being considered, such as their name, targets and representation requirements, and the penalty that should be applied if these representation requirements are not met.

The Planning Unit File contains information about the planning units themselves, such as ID number, cost, location and status.

The Planning Unit versus Conservation Feature File contains information on the distribution of conservation features in each of the planning units.

The Boundary Length File contains information about the length, or, effective length of shared boundaries between planning units. This file is necessary if you wish to use the Boundary Length Modifier to improve the compactness of reserve solutions, and while not required, is recommended.

The Block Definition File is very similar to the Conservation Feature File and can be used to set a series of default variable values for groups of conservation features.

More information about some potential ways to generate these files can be found in the tutorials contained in the User Manual's Appendix C (Edward T. Game, 2008).

Strengths and Challenges (Elizabeth Law, n.d.)

Table 13. Strengths and Challenges of Marxan and Marxan with Zones

Strengths	**Challenges**
Marxan solves large complex problems using simulated annealing. This is a powerful technique for solving allocation problems in very large solution spaces (exact methods are probably better for smaller problems: they require less parameterization, give exact outputs). Marxan can give several good solutions for the same problem, which can illustrate different policy options for achieving the same results. Marxan with Zones is a substantial development that allows specification of different "zones" or land uses, and allows differentiation of impact of different benefit features. This makes it flexible to analyze a greater range of contexts and questions.	When using Marxan, the quality of the output is subject to the quality of the data, the accuracy of the problem specification, and users' ability to parameterize the program, interpret, and communicate the results. In particular, ecosystem services that are derived from landscape scale characteristics (e.g. hydrology), can be challenging to specify. In order to incorporate uncertainty, users have to conduct sensitivity analysis, which can be cumbersome and sub-optimal. Preparing and formatting large datasets can be complicated.

B. Complementary Models

1) Just Land Use Modelling (No Valuation is Incorporated)

1. CLUE Model

The CLUE model is a dynamic, spatially explicit, land use and land cover change model. The Conversion of Land Use and its Effects modelling framework (CLUE) was developed to simulate land use change using empirically quantified relations between land use and its driving factors in combination with dynamic modelling of competition between land use types.

CLUE simulates land use conversion and change in space and time as a result of interacting biophysical and human drivers. Within CLUE, regional land use changes only if biophysical and human demands cannot be met by existing land use. After a regional assessment of land use needs, the final land use decisions are made on a local grid level. Important biophysical drivers are local biophysical suitability and their fluctuations, land use history, spatial distribution of infrastructure and land use, and the occurrence of pests and diseases. Important human land use drivers in CLUE are population size and density, regional and international technology level, level of affluence, target markets for products, economical conditions, attitudes and values, and the applied land use strategy (A. Veldkamp, 1996).

The original CLUE model cannot directly be applied at the regional scale. Therefore, the modelling approach has been modified and is now called CLUE-S (the Conversion of Land Use and its Effects at Small regional extent). CLUE-S is specifically developed for the spatially explicit simulation of land use change based on an empirical analysis of location suitability combined with the dynamic simulation of competition and interactions between the spatial and temporal dynamics of land use systems (Verburg).

More information and access to the software is available at:
http://www.ivm.vu.nl/en/Organisation/departments/spatial-analysis-decision-support/Clue/index.aspx

2. Ecopath with Ecosim (EwE)

Ecopath with Ecosim (EwE) is a free ecological/ecosystem modeling software suite that focuses on marine ecosystems, fisheries and environmental effects.

EwE has three main components: Ecopath – a static, mass-balanced snapshot of the system; Ecosim – a time dynamic simulation module for policy exploration; and Ecospace – a spatial and temporal dynamic module primarily designed for exploring impact and placement of protected areas. The Ecopath software package can be used to:

1. Assess the impacts of fishing on the ecosystem;
2. Predict movement and accumulation of contaminants and tracers (Ecotracer);
3. Explore management policy options;
4. Analyze impact and placement of marine protected areas;
5. Simulate the effects of environmental changes;
6. Answer ecological questions, and;
7. Facilitate end-to-end model construction (Ecopath International Initiative , n.d.).

More information and access to the software is available at http://ecopath.org/

2) Models That Model Specific Aspects of the Environment/ Watershed /Estuary

1. Assessment of Estuarine Trophic Status (ASSETS)

The National Estuarine Eutrophication Assessment/Assessment of Estuarine Trophic Status (NEEA/ASSETS) is a screening model that uses a Pressure-State-Response framework to assess eutrophication.

More information and access to the software is available at http://www.eutro.org/

2. Global Environmental Flow Calculator

The Global Environmental Flow Calculator can be used to determine the effects of river management on flow volumes. Healthy ecological functioning in rivers requires a minimum discharge. Users can therefore find the tool helpful to identify expected hydrological implications of land use planning, and make management decisions based on predicted flow regimes. A map interface allows the model user to view flow duration curves – graphical representations of the percentage of time that rivers or streams reach specific discharges (m3/s) – of six 'environmental management classes', ranging from "unmodified" to "critically modified" conditions, for their river of interest (Kastl, 2014).

More information and access to the software is available at: http://global-environmental-flow-calculator.sharewarejunction.com/

3. Open NSPECT

Open NSPECT stands for 'Open Nonpoint Source Pollution and Erosion Comparison Tool'. This tool estimates surface water volumes, pollutant concentrations, and sediment loads, mapping their spatial distribution on land and at the coastal interface. Land use scenarios can be used as input to predict future water quality in rivers, lakes, and marine bodies of water. Open NSPECT can therefore be used to analyze development strategies in order to select the ones that minimize negative impacts on water quality-enhancing ecosystem services and identify cost-effective solutions to restore these ecosystem services. Model outputs are nitrogen, phosphorous, and suspended solids, estimated for simulated land cover types (Kastl, Values Method Profile Open Nspect, 2014).

More information and access to the software is available at: https://coast.noaa.gov/digitalcoast/tools/opennspect

4. Soil and Water Assessment Tool (SWAT)

SWAT is a process-based, spatially semi-distributed watershed model. SWAT has been proven to be an effective tool for assessing water resources and non-point source pollution problems for a wide range of scales and environmental conditions across the globe. It is designed to evaluate how catchment hydrology and water quality are impacted by agricultural management practices such as crop rotations, tillage operations, fertilizer applications, or conservation practices such as terraces or filter strips. SWAT can be used to predict a wide range of biophysical variables at a daily resolution. SWAT outputs are also useful as indicators for several ecosystem services related to water (e.g. provisioning of fresh water, water purification) and biomass production (e.g. provisioning of food and/or bioenergy crops), as well as a tool to assess trade-offs among such services. (Strauch, 2014).

More information and access to the software is available at: http://swat.tamu.edu/

5. AGWA - Automated Geospatial Watershed Assessment Tool

The Automated Geospatial Watershed Assessment (AGWA) Tool is a GIS-based watershed management tool that parameterizes and runs two watershed models, SWAT and KINEROS2. AGWA provides qualitative estimates of runoff and erosion based on landscape change (Rey, 2012).

More information and access to the software is available at: http://www.tucson.ars.ag.gov/agwa/

6. The Source Loading and Management Model (WinSLAMM)

The Source Loading and Management Model (SLAMM) was designed to obtain a better understanding of the relationships between sources of urban runoff pollutants and runoff quality. The Source Loading and Management Model (SLAMM) includes a wide variety of source area and outfall control practices (infiltration practices, wet detention ponds, porous pavement, street cleaning, catch basin cleaning, and grass swales) (WinSLAMM-The Source Loading and Management Model, 2011).

More information and access to the software is available at: http://www.winslamm.com/

7. Assessing Flood Prevention Potential of Wetlands

This method can be used to estimate the capacity of wetlands to absorb excess water in cases of river flooding and thereby protecting downstream inhabitants. For this, the impact of water detention on peak flows is considered, as well as the extent and frequency of flood events, and how flooding affects people and their properties. Hydrological data are necessary (inflow to and outflow from a wetland). Basic calculations of differences provide first approximations of wetland's flood prevention potential. No modelling required. Maps show spatially explicit results (Schneider, 2014).

More information and access to the tool is available at: http://www.birdlife.org/worldwide/science/assessing-ecosystem-services-tessa

8. CanVis

CanVis is a visualization tool that coastal managers can use to model future changes that are related to sea level rise, storm surges and flooding. Visualizing the changes to ecosystems and built environment provides the opportunity to evaluate how future coastal changes will impact their landscapes and communities, helping planners to make smart decisions and prepare for and adapt to potential changes. The tool is easy to use, using controls that are similar to Photoshop, but also easier to learn (Office of Science and Technology Policy, Council on Environmental Quality, 2015) .

More information and access to the tool is available at: https://coast.noaa.gov/digitalcoast/tools/canvis.html

3) Useful Models/Tools with a Different Focus

1. RIOS - Resource Investment Optimization System

RIOS provides a standardized, science-based approach that is used to support the design of cost-effective investments in watershed services. It combines biophysical, social, and economic data to assist users with identifying 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. RIOS can facilitate the design of investments for a single management goal or several at once, including erosion control, water quality improvement (for nitrogen and phosphorus), flood regulation, groundwater recharge, dry season water supply, and terrestrial and freshwater biodiversity. RIOS is designed to address multiple ecosystem service objectives (e.g. erosion control, water quality regulation, seasonal flow & flood regulation), and can also be used to address biodiversity or other conservation or social objectives (e.g. poverty alleviation, alternative livelihoods) with user -defined inputs. The software is flexible enough to be applied in many different environmental, social, and legal contexts and can process and present scientific information in a way that is useful for managers (Schmidt, Values Method Profile RIOS, 2014).

More information and access to the software is available at:
http://www.naturalcapitalproject.org/software/#rios

2. Social Values for ES (SolVES)

SolVES (Social Values for Ecosystem Services) is a GIS application for assessing, mapping, and quantifying the social values which people attribute to publicly available benefits from nature, such as the beauty of a landscape, or the cultural or recreational value of a native forest. Shared social values (as opposed to private values) can be evaluated for various stakeholder groups, which may differ in their attitudes and preferences.

SolVES uses a combination of spatial and non-spatial responses to public value and preference surveys to derive a quantitative, 10-point, social-values metric, called the Value Index. It also calculates metrics characterizing the environment, such as dominant land cover and average distance to water. (Schmidt, Values Method Profile SOLVES, 2014) . More information and access to the software is available at: http://solves.cr.usgs.gov/

3. ES in Strategic Environmental Assessment

Strategic Environmental Assessment (SEA) is a structured process for decision support that offers a systematic way of regarding questions, issues and alternatives to be considered in governmental planning. Strategic Environmental Assessment (SEA) can be enhanced if environmental impacts or implications are expressed in terms of ecosystem services because the use of the ecosystem services concept in SEA offers a more holistic and integrated consideration of the socio-ecological system. This is necessary because the conservation of ecosystem services is essential to safeguard security, health, social relations and material needs – which are key concerns in governmental planning. It also provides a framework for communicating with stakeholders and decision-makers within the SEA process about environmental aspects in terms of their benefits for society (Geneletti, 2014). For more information, a guide is available at: http://www.ing.unitn.it/~genelab/documents/GuidelineESintoSEA.pdf

4) Models Under Development

1. **Polyscape** (Under Development)

Polyscape is an ecosystem service mapping approach that can identify areas of potential and actual ecosystem services generation by incorporating both local and expert knowledge to generate a representation of local landscape structures. It supports the engagement of different stakeholder groups and policy implementation across different sectors such as water, biodiversity, agriculture and forestry. Polyscape is designed to facilitate a more spatially sensitive and explicit implementation of policies and regulations. It is a multi-criteria GIS toolbox to identify and communicate synergies, trade-offs and opportunities related to ecosystem services under different land uses and protective actions. (Schmidt, Values Method Profile Polyscape, 2014).

For more information, a guide is available at: http://www.lucitools.org/

V. Vulnerability Assessment

A. Introduction

This section of the literature review draws extensively from Comparative Analysis of Climate Change Vulnerability Assessments: Lessons from Tunisia and Indonesia which was written by Anne Hammill, Livia Bizikovia, Julie, Dekens and Matthew McCandless from the International Institute for Sustainable Development (Anne Hammill, 2013). Although the paper was primarily about vulnerability assessments relating to climate change, the content could and has been adapted to a more general format so that it is applicable to performing vulnerability assessments to ecosystem services.

A vulnerability assessment is an approach that is used to identify the nature and extent of possible threats to humans or ecological systems. They help to create an understanding of how socio-ecological systems may be affected by a source of harm (hazard) in order to devise measures that can reduce or eliminate that harm.

B. Purposes of a Vulnerability Assessment

There are various purposes for conducting a vulnerability assessment:

1. To set mitigation targets: evaluate the impact of the hazard under different exposure scenarios in order to devise targets and timelines in order to avoid dangerous interference with the system of interest.
2. To allocate resources effectively: identify the systems that may be most affected by a hazard so that research activities and relevant financial and technical assistance can be channeled accordingly. Assessments for this purpose will include comparisons and prioritization exercises.
3. To design adaption policies: understand the vulnerability and capacity of the socio-ecological system (current and future) to adapt to different levels of exposure to the hazard in order to devise strategies that will minimize exposure and sensitivity and/or increase the system's adaptive capacity.
4. To monitor adaption policies: evaluate whether or not a specific adaption policy is actually reducing vulnerability.

5. To raise awareness about the hazard and its effects: highlight the causes, effects and ways to address the hazard through identification of the people, places, sectors that may be affected by the hazard, or causing higher levels of the hazard's exposure to the system. This is usually a secondary purpose for conducting a vulnerability assessment.
6. To conduct scientific research: gaining an understanding about vulnerability is about testing and refining methodologies, learning about system functioning, improving the theory about vulnerability and crafting modifications so that it can be applied to other systems. This is also usually a secondary purpose for conducting a vulnerability assessment.

A vulnerability assessment remains a very broad concept until the following questions can be answered to make it more specific:

1. Which system: What is the social/socio/ecological system being threatened?
2. Feature of concern: What is the valued feature within the vulnerable system that is potentially threatened (e.g. specific crop, human health)?
3. Type of hazard: What it the potentially damaging influence, which may adversely affect the valued feature of the system (e.g. changes in precipitation and temperature and its consequences like droughts or floods)?
4. Temporal reference: What is the time period of interest? Is the assessment considering current vulnerability of future vulnerability?

C. Approaches and Inputs

According to Hammill et al. 2013, there are different approaches to perform a vulnerability assessment:

1. Risk-hazard approach
2. Political economy approach
3. Integrated approach

A risk-hazard approach is considered a top-down or scenario driven vulnerability assessment. It is meant to specify what systems are vulnerable, what kinds of impacts may occur, when those impacts will occur, and where those impacts will occur. It is useful to describe the extent of the problem in terms of financial cost, ecosystem damage or lost lives.

A risk hazard approach looks at vulnerability in terms of the consequences (losses) that might be anticipated when exposed people/systems are sensitive to a particular hazard. Vulnerability is an outcome of a hazard interacting with an exposed entity that is sensitive to that particular hazard.

Hammill, et. al., comments that the risk-hazard approach is typically associated with the formula Risk=Hazard*Vulnerability. However, vulnerability in this context is a factor that shapes an outcome (risks/impact/expected losses of hazard) and refers to dose-response relationship which is captured by the term "sensitivity". Therefore, they suggest the formula should be revised to Impact=Hazard*Sensitivity.

The risk-hazard approach tend to use quantitative and top-down sources of information including computer generated projections, and impact models. The approaches for modelling include the following:

1. An indicator based approach which relies on available proxies,
2. A model-based approach which requires more data and analysis, and;
3. The use of impact-chains which depicts the cause and effect relationships between different components of the system.

The political economy approach focuses on the socio-economic processes that lead to different degrees of exposure, impacts, and capacities to deal with impacts. The political approach seeks to discover drivers of vulnerability and answer why populations are vulnerable, and why some groups are more affected by a hazard than others. The answers to these questions help to identify measures to reduce vulnerability, and the capacity and barriers that need to be considered for implementation of those measures.

The political economy approach generally uses a more qualitative, bottom up information, especially when the analysis is more localized at the community or household level.

The integrated approach draws concepts from the risk hazard approach and the political economy approach. It looks at vulnerability as the degree to which a system is susceptible or unable to cope with the adverse effects of a hazard's variability and extremes. It considers the system's differential exposure to the hazard, its sensitivity and adaptive capacity.

The integrated approach tends to use both quantitative and qualitative information at multiple scales.

The choice of which approach to use can be based on the research question being asked, the training of the research team, and the available resources and capacities.

Table 14. Simple Typology of Vulnerability Assessments According to Modeling Approaches and Respective Inputs

Vulnerability Assessment Approach	**Modelling Approach**	**What?**	**Inputs - Typically used data**	**Inputs - Methods**	**Inputs - Time and effort required**
Risk-hazard approach	Quantitative, model-based approaches	Modeling the system in view of climate change	Meteorological / climate data, biophysical	Climate/bio-physical Modeling	Usually high
Risk-hazard approach	Impact chain approaches	Deriving a qualitative model of the system	Can go potentially without data, or subsequent modeling	Expert judgement, or quantitative modeling	From low to high
Risk-hazard approach	Indicator-based approaches	Representing a system based on proxy-indicators	Socio-economic, biophysical, meteorological / climate data	Literature review; statistical analysis	From medium to high
Political economy approach	Bottom-up approaches	Describing the broader development context/ stressors on livelihood, climate only one of them	Historical data of weather & hazard impacts, livelihood data	Participative, qualitative (e.g. consultations, focus groups)	From low to high

Table adapted from: Comparative analysis of climate change vulnerability assessments: Lessons from Tunisia and Indonesia.

D. Outputs

The output of a vulnerability assessment can include the following:

1. Maps that depict the temporal and spatial distribution of the different determinants of vulnerability. These are a result of vulnerability assessment methodologies that overlay several vulnerability factors to identify 'hotspots' or the areas that are most vulnerable as a priority for policy implementation.
2. Reports that provide details about the methodology, results, interpretations and relevant policy recommendations.
3. Products that are a derivative of the reports such as policy briefs for decision makers, online resources or brochures for the interested public.

In order to be effective, the outputs must have the following important characteristics:

1. It must be given the appropriate interpretations. For example, a map of adaptive capacity for a population might lead to a false sense of security for the areas with a high capacity to adapt. However when other stressors are also mapped, these may overwhelm that area's capacity to adapt and leave the population worse off than other areas with a lower capacity to adapt.
2. It must be presented in a way that is usable to the users. The information must be represented at the temporal and spatial scales that are particular to the decision that needs to be made.
3. It must be presented in a way that is understandable and believable to the users/stakeholders.
4. Its source must be perceived as neutral and objective by the users/stakeholders.

E. How Does the Method Work?

Hammill, et. al., describes the steps in a vulnerability assessment as follows:

1. Define study area with stakeholders involvement: This includes selecting the spatial and temporal scale of the assessment, engaging intending beneficiaries and users of the vulnerability assessment, and considering the formats of the outputs that beneficiaries/users are able to receive and use
2. Get to know the place over time: This includes learning about the socio-ecological dynamics that influence vulnerability, performing literature reviews and having consultations about theses socio-ecological dynamics, as well as continued engagement of stakeholders.
3. Hypothesize who is vulnerable to what: Narrow down the key attributes such as the hazards, the specific ecosystem services/population being affected, as well as the data that represent these. At this stage, the analytical tools, required time and financial investments are considered.
4. Develop a causal model of vulnerability: Create the details for a model that explores and explains the factors, and relationships among that factors that result in vulnerability.
5. Find indicators for the elements of vulnerability: These indicators are metrics for key capacities, sensitivities, extent of the hazards within the defined focus of the vulnerability assessment. Seek suggestions from stakeholders about the metrics because these metrics need to be understandable to the stakeholders as well.
6. Operationalize model(s) of vulnerability: Use the indicators to obtain a composite measure of vulnerability. This can be done by weighting and combining indicators or overlay different indicators on a map. It requires coordination among researchers and stakeholders input in order to validate vulnerability measures.
7. Project future vulnerability: Assess how vulnerability might change with time across a range of scenarios using the relevant socio-economic, environmental variables. There should be a clear explanation about the assumptions and uncertainties involved in the scenarios.

8. Communicate vulnerability creatively: Create outputs such as reports, maps, websites, photos, video that are able to reach both decision-makers and stakeholders needed to implement vulnerability-reducing measures.

VI. Examples of Economic Valuation Results Used in Decision Making

This section discusses examples of economic valuation studies that were used for decision making, along with the outcomes of the decisions considered, based on the results from each study. This section first looks at four studies in which the outcome is discussed as part of the paper. Then the research team examined other studies, and their outcomes, that are referenced by other literature.

A. Economic Benefits of Standing Forests in Highland Areas of Borneo: Quantification and Policy Impacts

Authors

Robin Naidoo, Trent Malcolm, & Adam Tomasek

Background and Goals of the Study

The Indonesian government, in 2006, proposed to develop a series of oil palm plantations along the Kalimantan–Malaysian border on the island of Borneo. The potential economic benefits for an impoverished area of the country, was measured against the opportunity costs of developing oil palm plantations in the area. The areas possessed high species endemism, species new to science, and relatively intact, as well as ecosystem goods and services such as carbon storage, watershed protection, and non-timber forest products. Forest clearance would result in environmental damages such as increased erosion and chemical runoff from the plantations, as well as the ecological, social and economic costs of increased fire frequency (often used when establishing plantations) in the region.

Results

Using relatively simple statistical models, the researchers characterized relationships between standing forests in areas proposed as oil palm plantations and their economic values for three types of benefits: carbon storage, avoided health costs due to fires, and local forest–agroforest mosaics. Net present value (NPV) calculations based on different scenarios resulted in a mean carbon storage value of $2.7 billion, (± $1.8 billion), with a minimum of $500 million and a maximum of $7.1 billion. The avoided health costs due to fires was estimated to be $60,719 for Kalimantan and $5,746,179 for Sarawak in a normal year with an estimation that the numbers would triple in an El Nino year. Annual lost agroforestry revenues was estimated to be a minimum of $9.9 million (USD) and a maximum of $19.4 million (USD). Annual benefits of oil palm plantations were estimated to vary from $0 (assuming all labor is imported) to $227 million. The majority of the benefits of oil palm plantations were estimated to be a total of $3.7 billion, assuming net profits of $2078 per ha/year once plantations were fully operational. Additionally, harvesting the timber on site was estimated to provide one-time net revenues of $4.8 billion. Globally, benefits of cleaner-burning biodiesel from oil were estimated to be between $4 and $31 million.

How Results Informed Decisions

The analyses were used to point out the economic values of standing forests (as opposed to the benefits of oil palm plantations) to a variety of stakeholders, including within the Indonesian Ministries of Forestry, Economics, Agriculture, Environment and Planning, and Public Works, as well as with local government officials, community and indigenous groups, and Indonesian nongovernmental organizations. These discussions led to recommendations that were sent to the President of Indonesia by the National Planning Agency as a template for national policy. The World Wildlife Fund (WWF) also met directly with the President. The estimated values of ecosystem goods and services were one of the reasons mentioned in the discussion for not clearing the vast areas of forest. The value of ecosystem services was also included as one of the references by the Ministry of Agriculture, Ministry of Defense and West Kalimantan Provincial Government when they declared that the oil palm development would not go forward because the Heart of Borneo "is a resource of life for Kalimantan. This valuation work on the policy was used in conjunction with other arguments for shelving the proposal.

B. Integrating Ecosystem-Service Tradeoffs Into Land-use Decisions

Authors

Joshua H. Goldstein, Giorgio Caldarone, Thomas Kaeo Duarte, Driss Ennaanay, Neil Hannahs, Guillermo Mendoza, Stephen Polasky, Stacie Wolny, and Gretchen C. Daily

Background and Goals of the Study

The largest private landowner in Hawaii, Kamehameha Schools, wanted to design a land-use development plan that reflected the best use of the largely abandoned agricultural lands (on its North Shore land holdings (Island of O'ahu) of ~10,600 population) in order to meet the needs of the local community and those of the broader public, while also generating positive financial return for Kamehameha Schools. The landowner needed to consider alternative land uses in order to decide whether to invest an estimated $7.0 million to improve the region's aging irrigation system to sustain and enhance agricultural production, or to pursue other options instead.

Results

The researchers used the InVEST software tool to evaluate the environmental and financial implications of seven planning scenarios including land-use combinations including biofuel feedstocks, food crops, forestry, livestock, and residential development. All scenarios produced positive financial return relative to the status quo of negative return. However, tradeoffs existed between carbon storage and water quality, as well as between environmental improvement and financial return.

How Results Informed Decisions

Based on the analysis and community input, Kamehameha Schools implemented a plan to support diversified agriculture and forestry. This plan provided a positive financial return ($10.9 million) and improved carbon storage (0.5% increase relative to status quo) with negative relative effects on water quality (15.4% increase in potential nitrogen export relative to status quo). The effects on water quality could be mitigated partially (reduced to a 4.9% increase in potential nitrogen export) by establishing vegetation buffers on agricultural fields.

C. Embedding Ecosystem Services in Coastal Planning Leads to Better Outcomes for People and Nature

Authors

Katie K. Arkema, Gregory M. Verutes, Spencer A. Wood, Chantalle Clarke-Samuels, Samir Rosado, Maritza Canto, Amy Rosenthal, Mary Ruckelshaus, Gregory Guannel, Jodie Toft, Joe Faries, Jessica M. Silver, Robert Griffin, and Anne D. Guerry

Background and Goals of the Study

Although there are numerous possible uses for the coastal zone in Belize, lack of information and tools and limited local capacity stalled the development of an integrated management plan, and legislation was passed in 1998 mandating multi-sectoral planning. In 2010, Belize's Coastal Zone Management Authority (CZMAI) partnered with NatCap and the World Wildlife Fund (WWF) to explore where Belize should site coastal and ocean uses to reduce risk to marine ecosystems and enhance benefits they provide to people (MEAM Staff, 2016).

Results

The researchers developed models that quantified services provided by corals, mangroves, and seagrasses. These models were used within an extensive engagement process to design a national spatial plan for Belize's coastal zone through iteration of modeling and stakeholder engagement. The plan is under formal consideration by the Belizean government.

How the Results Informed Decisions

An outcome of the project was an Informed Management Zoning Scheme that blended development and conservation goals while considering the needs of multiple sectors and stakeholders and explicitly accounting for nature's benefits to people. It is under review by the Belize National Assembly, and lessons from this planning process are being applied in other areas such as Mozambique, Barbados, Woods Hole, MA in the U.S. (MEAM Staff, 2016).

D. Ecosystem Services Modelling as a Key Input for Decision Making in the Water for São Paulo Movement

Authors

Joao Guimaraes, Gilberto Tiepolo, Samuel Barreto

Background and Goals of the Study

The Cantareira Water Supply System provides water to 50% of the São Paulo Metropolitan Area population (9 million people). However, it lost 70% of its original forest cover, which has contributed to soil erosion, polluted waterways, change in seasonal water flow, and a decline in water quality. Restoration and protection of ecosystems in these critical watersheds can provide a significant increase of ecosystem services that millions of people rely upon to meet their basic water needs. Therefore, the Water for São Paulo Movement performed research to provide a technical basis for supporting decision-making on the best alternatives for land use management, with the goal of ameliorating or preserving hydrological ecosystems services. This was accomplished by: 1) identifying areas of high erosion and sediment delivery to prioritize for activity implementation, and; 2) estimating the total benefit that restoration and conservation activities could have on erosion and sediment delivery.

Results

The researchers found that, although the erosion rate was not being dramatically reduced on average, by targeting interventions to critical areas meant that sediment delivery to streams could be significantly improved. This is because riparian areas and places with steep slopes, if covered with forests or other natural vegetation, would trap most of the soil detached locally and upslope and prevent it from reaching water bodies below. By doing this prioritized kind of intervention, they were able to obtain impressive gains in terms of sedimentation reduction to increase water quality, with smaller efforts of restoration.

How the Results Informed Decisions

The Nature Conservancy presented this study to several key stakeholders in São Paulo. It has also been cited by several authors, and taken up by various organizations such as the

State Government of São Paulo; the Watershed Basins Committees in Piracicaba, Capivari, Jundiai (where environmental guidelines and payment for ecosystem services have been approved), and the Alto Tietê Committee, who have disseminated the results and implemented new environmental guidelines. The researchers reported that using science-based studies to support watershed management was key in attracting the interest and support of the private sector, in collaborative watershed partnerships.

E. Other Studies and Their Outcomes

In addition to the research papers that are explored above, case studies about environmental valuation are discussed in other presentations or reports.

In Spain, the Spanish National Hydological Plan (SNHP) included a transfer of 1,050 cubic hectometers from the Lower Ebro River in the north of the country for urban and agricultural uses. A cost-benefit study that took into account ecosystem goods and services determined the SNHP had a negative bet benefit of 3.5 billion Euros. Therefore, the new government cancelled SNHP and sought different methods to solve the water problems such as desalination, reuse of waste water and improved use of ground water (The World Conservation Union).

Additionally, Kushner et al. (2012) reported the results of interviews conducted with more than thirty marine conservation and valuation experts from which they were able to identify valuation studies that influenced policy involving tropical marine ecosystems. These findings were reproduced by this study research team, and presented in the following table.

Table 15. Studies that Influenced Policy Involving Tropical Marine Ecosystems

Country	Study Site	Ecosystem	Ecosystem Services Valued	Influence	Study Reference
Bahamas	Andros Island	Coral reefs / beaches / wetlands / forest / mangroves	Use & Non-Use	Justified the protection of the west side of Andros Island. The Bahamas Science and Technology Commission is also using the results to inform coral reef damage estimates; furthermore, valuation results are being used to raise awareness of the economic benefits of conservation to decision makers and the general public.	Hargreaves-Allen (2010)
Belize	National level	Coral reefs / mangroves	Tourism / Fisheries / Shoreline protection	Supported action on multiple fronts, including a landmark Supreme Court ruling to fine a ship owner an unprecedented and significant sum for a grounding on the Mesoamerican Reef; the government's decision to enact a host of new fisheries regulations (a ban on bottom trawling, the full protection of parrotfish, and the protection of grouper spawning sites); and a successful civil society campaign against offshore oil drilling.	Cooper et al. (2009)

Table 15. Studies that Influenced Policy Involving Tropical Marine Ecosystems, Cont.

Country	Study Site	Ecosystem	Ecosystem Services Valued	Influence	Study Reference
Belize	Gladden Spit Marine Reserve	Coral reefs	Tourism / Fisheries	Justified funding requests for ongoing planning and management of the Gladden Spit Marine Reserve, resulting in increased donations; additionally, valuation results helped the Gladden Spit Marine Reserve facilitate a historically strained dialogue with fishers and tour operators.	Hargreaves-Allen (2008)
Dominican Republic	La Caleta Marine Reserve	Coral reefs	Dive tourism	Findings used to justify significant increase in user fees. Additional revenue has been used to help establish an aquatic center, a conservation fund to support park management, and a community fund to support local development projects.	Wielgus et al. (2010)
Mexico	Cancun	Coral Reefs	Tourism	Justified the collection and distribution of revenues from tourist user fees to support local MPAs	Rivera-Planter et al. (2005)
Netherlands	Bonaire National Marine Park	Coral Reefs	Dive Tourism	Justified the Bonaire Marine Park's adoption, and later increase, of user fees, making it one of the few self-financed marine parks in the Caribbean.	Dixon et al. (1993); Uyarra et al. 2010); Thur (2010)

Table 15. Studies that Influenced Policy Involving Tropical Marine Ecosystems, Cont.

Country	Study Site	Ecosystem	Ecosystem Services Valued	Influence	Study Reference
St. Maarten	The Man of War Shoal Marine Park	Coral reefs	Tourism / Fisheries	Used by the government of St. Maarten's to establish the Man of War Shoal Marine Park—the country's first national park; furthermore, the valuation results are currently being used to sue for damages caused by the sinking of a boat inside the Man of War Shoal Marine Reserve	Bervoets (2010); WRI 2008a (tourism); WRI 2008b (fisheries)
United States	Florida	Beaches	Tourism	Helped justify the passage of a US$4 billion Save our Coast Trust Fund to buy up beaches in order to provide access to the public.	Bell (1986)
United States	Florida	Coral Reefs	Recreational Fisheries	Justified the issuance of state-wide saltwater fishing licenses, which raised revenue for enforcement.	Bell et al. (1982)
United States	Hawaii / Big Island and Maui	Coral reefs	Use & non-use	Supported the creation of a Reef Fund for dive and snorkel operators to collect voluntary donations from clients to fund marine protection programs.	Slootweg et al. (2008); Beukering et al. (2004)
United States	Hawaii	Coral reefs	Use & non-use	Justified the establishment of administrative penalties for damage to coral reefs in Hawaii.	Slootweg et al. (2008); Cesar et al. (2000)

Table 15. Studies that Influenced Policy Involving Tropical Marine Ecosystems, Cont.

Country	Study Site	Ecosystem	Ecosystem Services Valued	Influence	Study Reference
United States	Florida	Marine Reserves	Tourism/ Fisheries	Supported the design of the regulatory alternatives adopted by government agencies, including the Tortugas Ecological Reserve; Florida Keys National Marine Sanctuary; furthermore, the integration of socioeconomic information has resulted in increased regulatory compliance, lower enforcement costs, and the development of cooperative management processes with stakeholders.	Leeworthy and Wiley (2000); NOAA (1997)
United States	Florida Keys National Marine Sanctuary	Coral Reefs	Tourism	Justified a schedule of escalating fines for injury to living coral based on the area of impact; as a result, the Florida Keys National Marine Sanctuary has recovered millions of dollars for reef restoration after ship groundings.	Leeworthy (1991)

Table 15. Studies that Influenced Policy Involving Tropical Marine Ecosystems, Cont.

Country	Study Site	Ecosystem	Ecosystem Services Valued	Influence	Study Reference
Philippines	Palawan Island	Coral reefs	Fisheries / Dive tourism	Banned logging in Palawan, established EL Nido Managed Resources Protected Area (a marine reserve), and promoted eco-tourism development.	Cesar (2000); Hodgson et al. (1988)
Philippines	Pagbilao Mangrove forest	Mangroves	Carbon Storage	Highlighted the benefits of wetlands as carbon sinks, which helped to justify investments in mangrove reforestation — particularly from the private sector.	Slootweg et al. (2008); Janssen et al.(1999)
Sri Lanka	National Level	Coral Reefs	Tourism	Supported a ban on coral mining in Sri Lanka, which was adopted; additionally, influenced the development of national strategies to promote conservation, including Coastal Zone Management plans (which are updated every five years).	White et al. (1997)

Literature Cited

Office of Science and Technology Policy, Council on Environmental Quality. (2015, October 13). *CanVis*. Retrieved June 6, 2016, from U.S. Resilience Toolkit: https://toolkit.climate.gov/tool/canvis

Office of Science and Technology Policy, Council on Environmental Quality. (2015, October 14). *U.S. Climate Resilience Toolkit*. Retrieved from Multiscale Integrated Models of Ecosystem Services (MIMES): https://toolkit.climate.gov/tool/multiscale-integrated-earth-systems-model-mimes-0

A. Veldkamp, L. F. (1996). CLUE: a conceptual model to study the Conversion of Land Use and its Effects. *Ecological Modelling* , 253-270.

AFORDable Futures. (n.d.). *How To Use MIMES Intro Folder.* Retrieved from AFORDable Futures LLC: https://docs.google.com/document/d/16RsabbWaQ48zVxuBwTGn_ZTgQZj3R0ISGCO9zTsqkFQ/edit

AFORDable Futures. (n.d.). *Training* . Retrieved from AFORDable Futures LLC: http://www.afordablefutures.com/orientation-to-what-we-do/services/training

Anne Hammill, L. B. (2013). *Comparative Analysis of Climate Change Vulnerability Assessments: Lessons from Tunisia and Indonesia.* Bonn and Eschborn, Germany: Deutsche Gesellschaft fur Internationale Zusammenarbeit (GIZ) GmbH.

Bell, F. (1986). *An Economic Analysis of the Importance of Saltwater Beaches in Florida.* Gainesville, Florida: Florida Sea Grant College.

Bell, F. P. (1982). *The Economic Impact and Valuation of Saltwater Recreational Fisheries in Florida.* Gainesville, Florida: Florida Sea Grant College.

Bervoets, T. (2010). *Working Paper on the Economic Valuation of Country St. Maarten's Coral Reef Resources.* St. Maarten, Netherland Antilles: Nature Foundation St. Maarten.

Beukering, P. v. (2007). *Valuing the Environment in Small Islands: An Environmental Economics Toolkit.* Peterborough, UK: Joint Nature Conservation Commitee.

Cesar, H. S. (2000). *Collected Essays on the Economics of Coral Reefs.* Sweden: CORDIO.

Cooper, E. L. (2009). *Coastal Capital: The Economic Contribution of Belize's Coral Reefs and Mangroves.* Washington, DC: World Resources Institute.

Dixon, J. L. (1993). *Meeting Ecological and Economic Goals: Marine Parks in the Caribbean.* Ambio 22 (2/3): 117-125.

Earth Economics. (2010). *Nature's Value in the Terraba-Sierpe National Wetlands.* Tacoma, WA: Earth Economics.

Ecopath International Initiative . (n.d.). *Home*. Retrieved from Ecopath with Ecoism: http://ecopath.org/

Ecosystems Knowledge Network . (n.d.). *Costing Nature* . Retrieved from Ecosystems Knowledge Network : http://ecosystemsknowledge.net/coting-nature

Edward T. Game, H. S. (2008). Marxan User Manual: For Marxan Version 1.8.10. University of Queensland, St. Lucia, Queensland, Australia, and Pacific Marine Analysis and Research Association, Vancouver, British Columbia, Canada.

Elizabeth Law, R. R. (n.d.). *Values Method Profile- Marxan*. Retrieved from About Values: http://www.aboutvalues.net/data/method_navigator/values_method_profile_marxan.pdf

Forkink, A. (2015). *Ecosystem Services Assessments As a Planning Tool in Florida.*

Förster, J. (n.d.). *Values Method Profile -InVEST General.* Retrieved from About Values : http://www.aboutvalues.net/data/method_navigator/values_method_profile_invest_general.pdf

Geneletti, D. (2014, July). *Values Method Profile SEA.* Retrieved from About Values: http://www.aboutvalues.net/data/method_navigator/values_method_profile_sea.pdf

Hargreaves-Allen, V. (2008). *The Economic Value of the Gladden Spit.* Conservation Strategy Fund.

Hargreaves-Allen, V. (2010). *The Economic Valuation of Natural.* Conservation Strategy Fund.

Hodgson, G. a. (1988). *Logging Versus Fisheries and Tourism in Palawan.* Honolulu: East-West Environment and Policy Institute.

Janssen, R. a. (1999). *Preservation or Conservation? Valuation and Evaluation of a Mangrove Forest in the Phillipines.* Environmental and Resource Economics 14 (3): 1573–02.

Joao Guimaraes, G. T. (2015). *Ecosystem Services Modelling as a Key Input for Decision Making in the Water for São Paulo Movement.*

Joshua H. Goldstein, G. C. (2012). *Integrating Ecosystem-Service Tradeoffs Into Land-use Decisions.* PNAS.

Kastl, B. (2014, July). *Values Method Profile Flow Calculator.* Retrieved from About Values: http://www.aboutvalues.net/data/method_navigator/values_method_profile_global_flow_calculator.pdf

Kastl, B. (2014, July). *Values Method Profile Open Nspect.* Retrieved from About Values: http://www.aboutvalues.net/data/method_navigator/values_method_profile_open_nspect.pdf

Katie K. Arkema, G. M.-S. (2015). *3) Embedding Ecosystem Services in Coastal Planning Leads to Better Outcomes for People and Nature.* PNAS.

King's College, A. (n.d.). *Training* . Retrieved from Policy Support : http://www.policysupport.org/costingnature/training

King's College, AmbioTek. (n.d.). *Home*. Retrieved from Policy Support: http://www.policysupport.org/home

Kushner, B. R. (2012). *Influence of Coastal Economic Valuations in the Caribbean: Enabling Conditions and Lessons Learned.* Washington D.C. : World Resources Institute.

Leeworthy, V. R. (1991). *Recreational Use Value for John Pennekamp Coral Reef State Park and Key Largo National Marine Sanctuary.* Rockville, MD: National Oceanic and Atmospheric Administration.

Leeworthy, V. R. (2000). *Proposed Tortugas 2000 Ecological Reserve: Final Socioeconomic Impact Analysis of Alternatives.* Silver Spring, MD: National Oceanic and Atmospheric Administration.

MEAM Staff. (2016, February 1). *The EBM Toolbox: Using decision support tools for Coastal Zone Management in Belize*. Retrieved from Marine Ecosystems and Management: https://meam.openchannels.org/news/meam/ebm-toolbox-using-decision-support-tools-coastal-zone-management-belize

Muller, S. (n.d.). *Values Method Profile - Costing Nature*. Retrieved from About Values: http://www.aboutvalues.net/data/method_navigator/values_method_profile_costingnature.pdf

NatCap. (n.d.). *InVEST*. Retrieved from The Natural Capital Project: http://www.naturalcapitalproject.org/invest/

NatCap. (n.d.). *Our Training Program*. Retrieved from The Natural Capital Project: http://www.naturalcapitalproject.org/training-program/

National Oceanic and Atmospheric Administration. (n.d.). *Southern California Beach Valuation Project*.

Rey, D. R. (2012, October 1). *AGWA - Automated Geospatial Watershed Assessment Tool*. Retrieved from Ecosystem-Based Management Tools Network: https://ebmtoolsdatabase.org/tool/agwa-automated-geospatial-watershed-assessment-tool

Richard Waite, L. B. (2014). *Coastal Capital: Ecosystem Valuation for Decision Making in the Caribbean .* Washington, D.C.: World Resources Institute.

Rivera-Planter, M. a.-P. (2005). *Fees for Reefs: Economic Instruments to Protect Mexico's Marine Natural Areas.* Tourism 8 (2–3): 195–213.

Robin Naidoo, T. M. (2009). *Economic Benefits of Standing Forests in Highland Areas of Borneo: Quantification and Policy Impacts.* Conservation Letters 2 .

Schmidt, S. (2014). *Values Method Profile Polyscape.* Retrieved from About Values: http://www.aboutvalues.net/data/method_navigator/values_method_profile_polyscape.pdf

Schmidt, S. (2014, July). *Values Method Profile RIOS.* Retrieved from About Values: http://www.aboutvalues.net/data/method_navigator/values_method_profile_rios.pdf

Schmidt, S. (2014, July). *Values Method Profile SOLVES.* Retrieved from About Values: http://www.aboutvalues.net/data/method_navigator/values_method_profile_solves.pdf

Schmidt, S. (n.d.). *Values Method Profile - ARIES.* Retrieved from About Values: http://www.aboutvalues.net/data/method_navigator/values_method_profile_aries.pdf

Schmidt, S. (n.d.). *Values Method Profile ARIES*. Retrieved from About Values: http://www.aboutvalues.net/data/method_navigator/values_method_profile_aries.pdf

Schmidt, S. (n.d.). *Values Method Profile- MIMES.* Retrieved from About Values: http://www.aboutvalues.net/data/method_navigator/values_method_profile_mimes.pdf

Schneider, A. (2014, July). *Values Method Profile Flood Prevention Wetlands.* Retrieved from About Values: http://www.aboutvalues.net/data/method_navigator/values_method_profile_flood_prevention_wetlands.pdf

Sharp, R. T.-K. (2015). *InVEST +VERSION+ User's Guide.* The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund.

Slootweg, R. a. (2008). *Valuation of Ecosystem Services & Strategic Environmental Assessment: Lessons from Influential Cases.* Utrecht, Netherlands: Netherlands Commission for Environmental Assessment.

South African Water Research Commission . (n.d.). *Introduction to Estuary Ecosystem Services.* Retrieved May 17, 2016, from South African Water Research Commission : http://www.wrc.org.za/Lists/Knowledge%20Hub%20Items/Attachments/9714/Estuary%20Ecosystem%20Services%20Report.pdf

Strauch, M. (2014, July). *Values Method Profile - SWAT.* Retrieved from About Values: http://www.aboutvalues.net/data/method_navigator/values_method_profile_swat.pdf

The World Conservation Union . (n.d.). *Application of Valuation in Decision-Making.* Retrieved from Earthmind: http://earthmind.net/rivers/docs/iwl-talk-applications-iucn.pdf

Thur, S. (2010). *User Fees as Sustainable Financing Mechanisms for Marine Protected Areas.* Marine Policy 34: 63–69.

University of Queensland . (n.d.). *Brief History of Marxan* . Retrieved from University of Queensland : http://www.uq.edu.au/marxan/index.html?page=78877&p=1.1.3.2

University of Queensland . (n.d.). *How to Use Marxan* . Retrieved from University of Queensland : http://www.uq.edu.au/marxan/index.html?page=77652&p=1.1.3.3

University of Vermont, Earth Economics Conservation International. (n.d.). *How Do I Use ARIES.* Retrieved from ARtificial Intelligence for Ecosystem Services: http://aries.integratedmodelling.org/?page_id=940

University of Vermont, Earth Economics, Conservation International . (n.d.). *Training* . Retrieved from ARtificial Intelligence Ecosystem Services: http://aries.integratedmodelling.org/?page_id=120m

University of Vermont, Earth Economics, Conservation International. (n.d.). *Making Science Matter in Decision Making.* Retrieved from ARtificial Intelligence for Ecosystem Services: http://aries.integratedmodelling.org/?page_id=632

University of Vermont, Earth Economics, Conservation International. (n.d.). *Technology for 21-Century Ecosystem Services Science.* Retrieved from ARtificial Intelligence for Ecosystem Services: http://aries.integratedmodelling.org/?page_id=77

University of Vermonth, Earth Economics, Conservation International. (n.d.). *ARtificial Intelligence for Ecosystem Services History*. Retrieved from ARtificial Intelligence for Ecosystem Services: http://aries.integratedmodelling.org/?page_id=763

Uyarra, M. J. (2010). *Charging for Nature: Marine Park Fees and Management from a User Perspective.* Ambio 39: 515–23.

Verburg, P. (n.d.). *The CLUE Modelling Framework .* Retrieved from Institute for Environmental Studies at VU University Amsterdam: http://www.ivm.vu.nl/en/Images/Exercises_tcm234-284019.pdf

White, A. V. (1997). *Using Integrated Coastal Management and Economics to Conserve Coastal Tourism Resources in Sri Lanka.* Ambio 26 (6): 335–44.

Wielgus, J. E. (2010). *Coastal Capital: Dominican Republic. Case Studies on the Economic Value of Coastal Ecosystems in the Dominican Republic.* Washington DC: World Resources Institute.

WinSLAMM- The Source Loading and Management Model. (2011, April 18). Retrieved from Ecosystems-Based Management Tools Network: https://ebmtoolsdatabase.org/tool/winslamm-source-loading-and-management-model

World Resources Institute. (2008a). *Tourism and Recreation Valuation Tool.* Washington DC: World Resources Institute.

World Resources Institute. (2008b). *Fisheries Valuation Tool.* Washington, DC: World Resources Institute.