InVEST

Integrated **V**aluation of **E**nvironmental **S**ervices and **T**radeoffs

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www.amure.fr

Topics

1. Ecosystem Services
2. What is InVEST?
3. Available models
4. Description of some models
    - Provisioning
    - Cultural
    - Supporting
    - Regulating

5. Case study
6. Discussion

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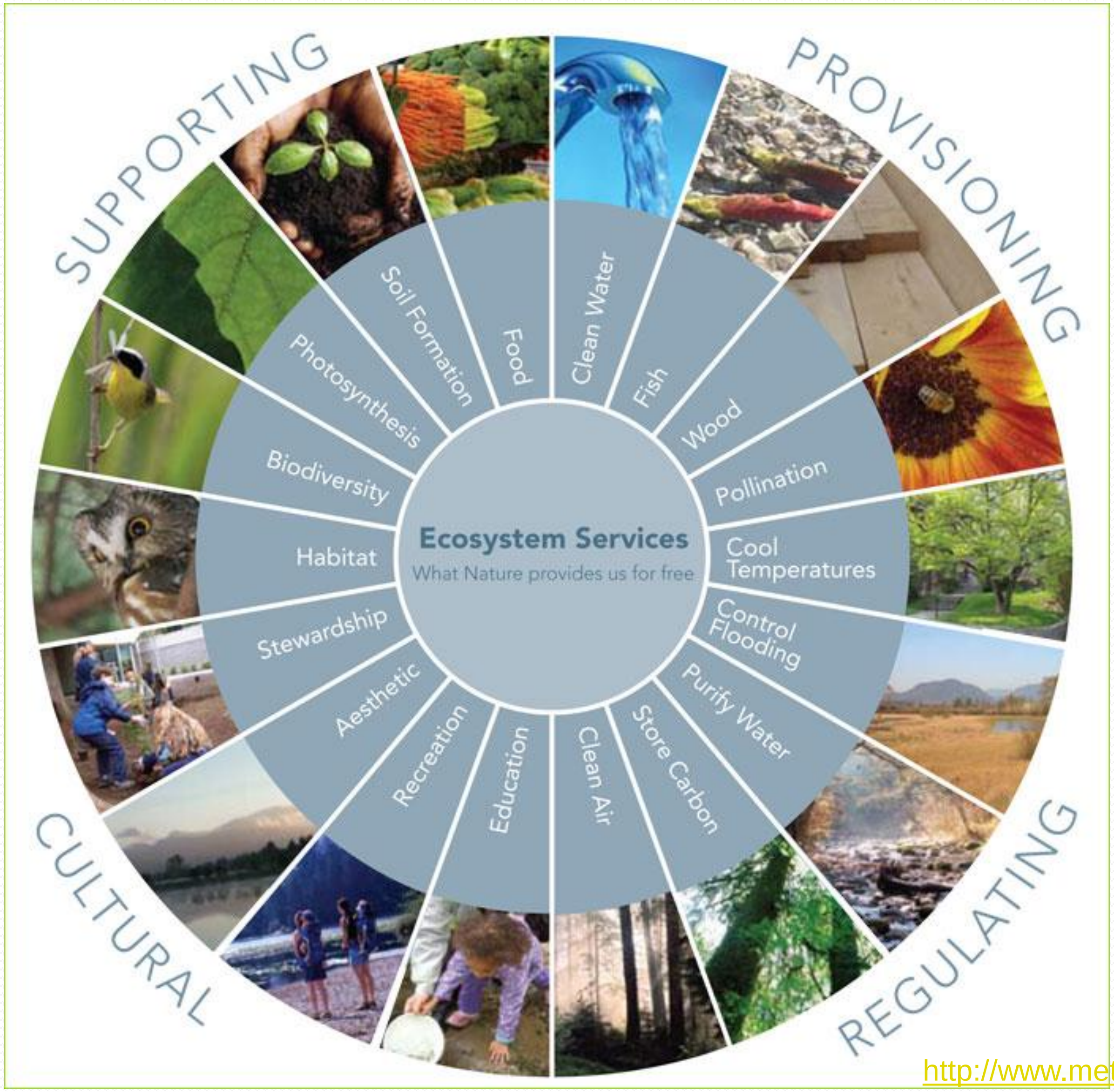
1. Ecosystem Services



http://www.metrovancouver.org, 2013

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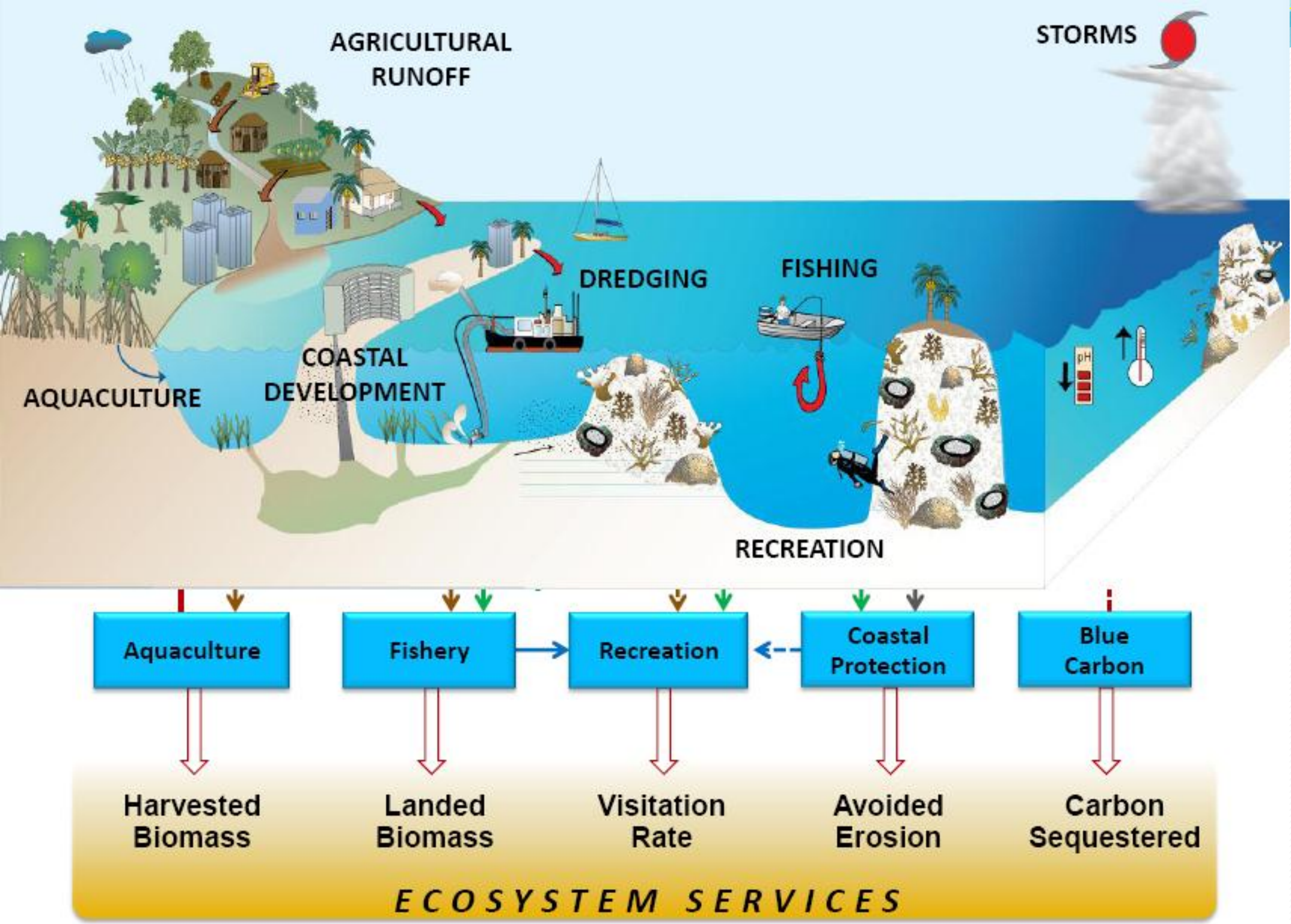

(Greg Verutes, 2012)

2. What is InVEST?

- **InVEST** is a framework of « open source » models for mapping and valuing ES
- **Integrates** multiple ES
- **Spatially** explicit (GIS)
- Decision support **scenarios**
- Economic and biophyisic **valuation**
- Developed by Natural Capital Project (http://www.naturalcapitalproject.org)

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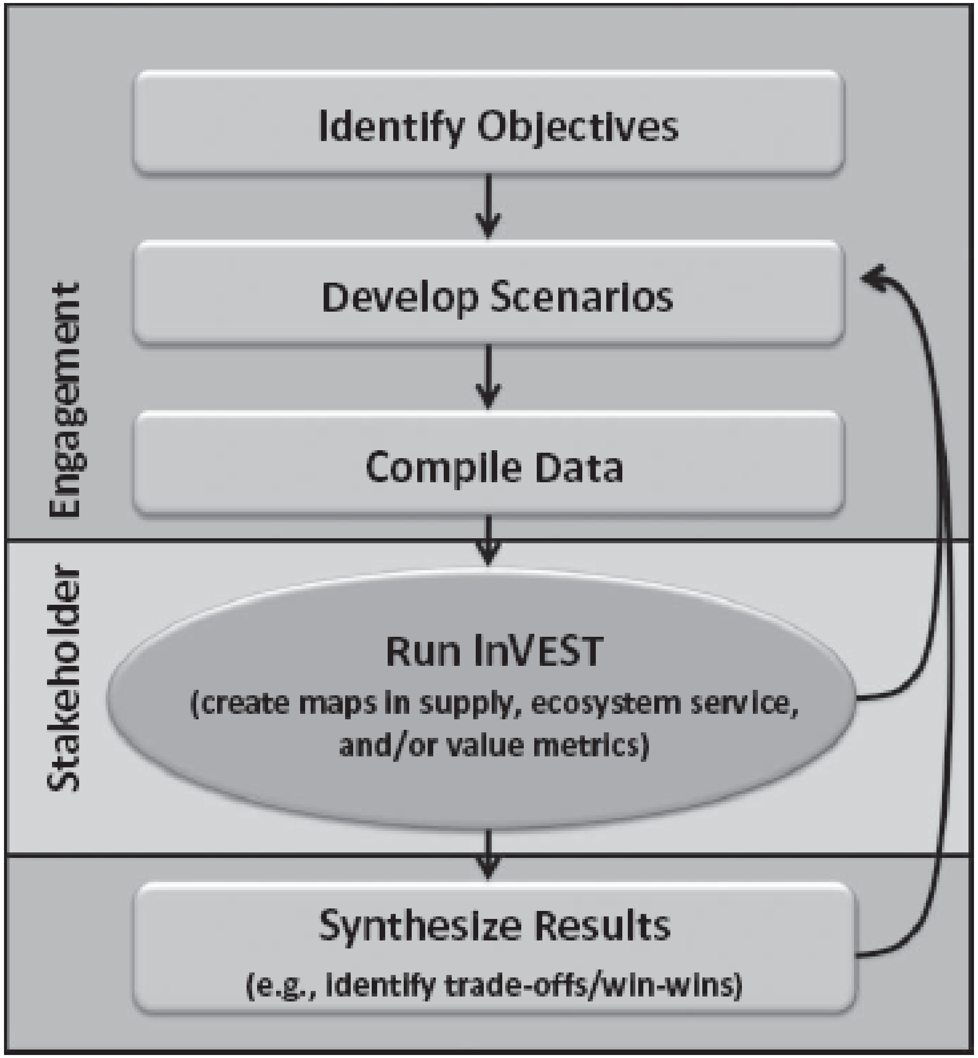
Woods Institute for the Environment Stanford University

WWF

The Nature Conservancy

Institute on the Environment University of Minnesota Driven to Discover

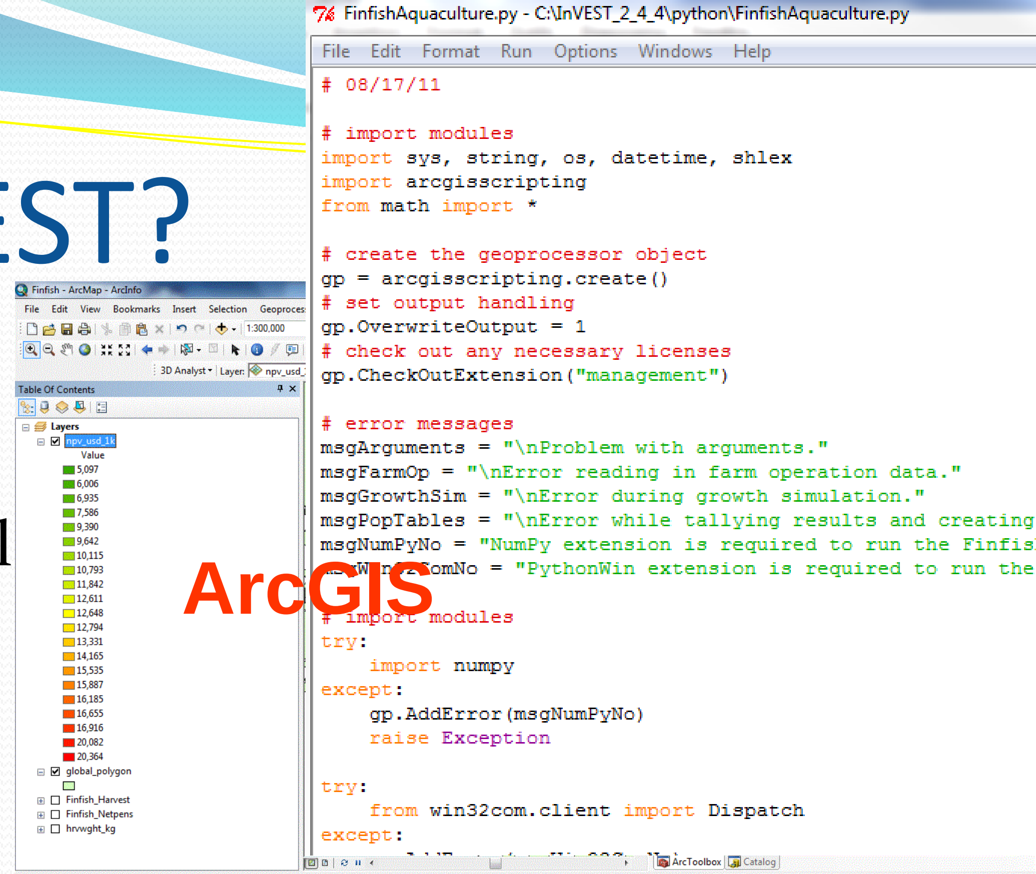
2. What is InVEST?

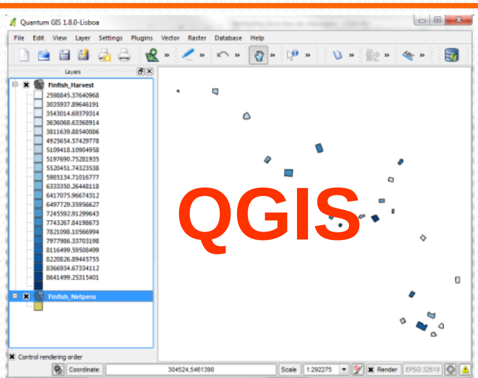


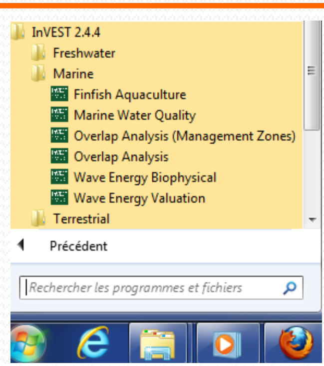
(Guerry et al 2012)

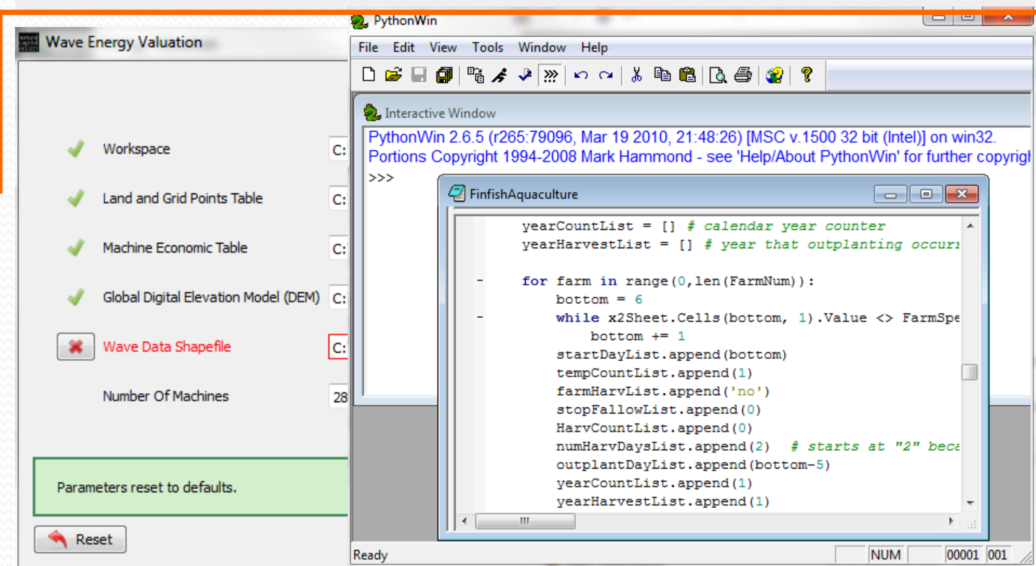
2. What is InVEST?

- Version 2.4.4
- Regular updates
- **ArcGIS** ArcView with Spatial Analyst
- *Open source* with **Python**
- Also works in stand-alone mode
- QGIS, gvSIG...



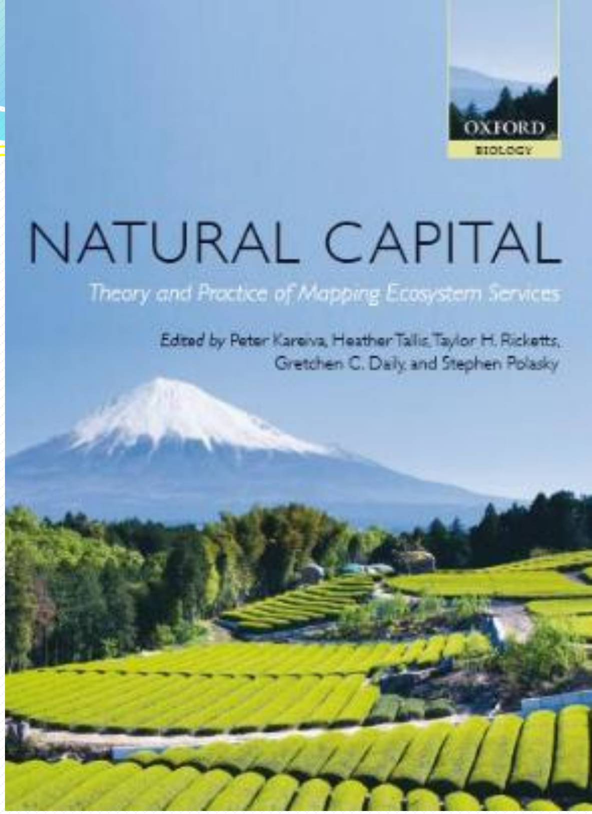


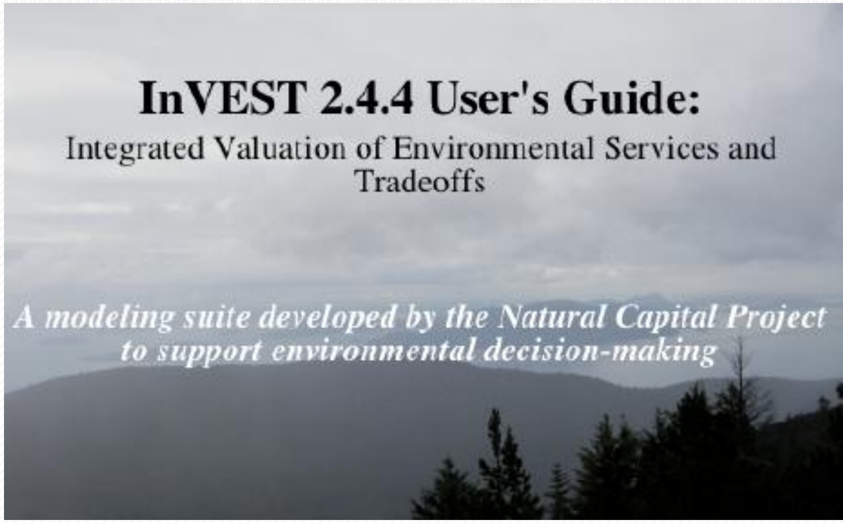




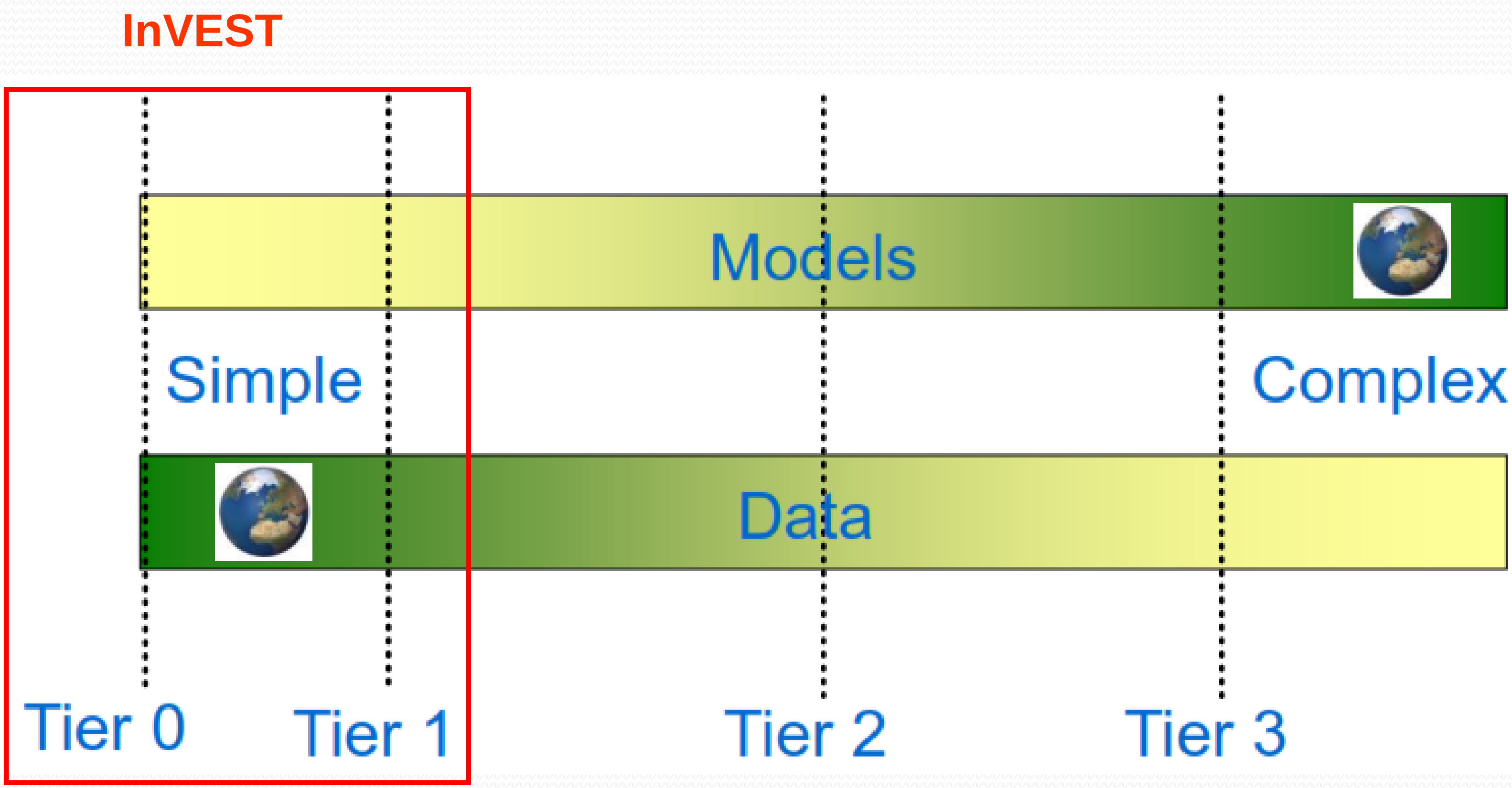
2. What is InVEST?

- Software
  http://www.naturalcapitalproject.org/InVEST.html
- Forum
  http://invest.ecoinformatics.org/
- Mailing list:
  https://mailman.stanford.edu/mailman/listinfo/invest-users





3. Available models



- **15 models**: freshwater, marine and terrestrial

AESTHETIC QUALITY
Maps the visibility of features on a seascape or landscape

BIODIVERSITY
Characterizes habitat quality and quantifies relative habitat loss

CARBON
Quantifies and values carbon storage and sequestration in terrestrial ecosystems

COASTAL PROTECTION
Quantifies and values the benefits of nearshore habitats for coastal protection

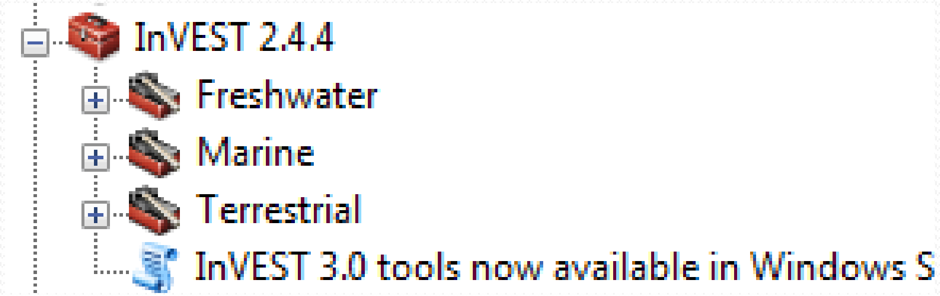
COASTAL VULNERABILITY
Assesses the relative risk to coastal areas from storms

CROP POLLINATION
Quantifies and values the contribution of wild pollinators to agricultural production

HABITAT RISK ASSESSMENT
Evaluates the risk to marine or terrestrial habitats from anthropogenic factors

MANAGED TIMBER PRODUCTION
Values timber harvest

MARINE FISH AQUACULTURE
Estimates the harvest weight and value of farmed salmon



MARINE WATER QUALITY
Models concentration of pollutants at sea

OVERLAP ANALYSIS
Identifies areas of potential conflict between various human uses

RESERVOIR HYDROPOWER PRODUCTION
Quantifies the amount and value of hydropower produced by a reservoir

SEDIMENT RETENTION
Quantifies soil loss and retention and values the avoided cost of water treatment or dredging

WATER PURIFICATION
Quantifies nutrient retention, and values the avoided cost of water treatment

WAVE ENERGY
Models and values harvested energy from wave power facilities

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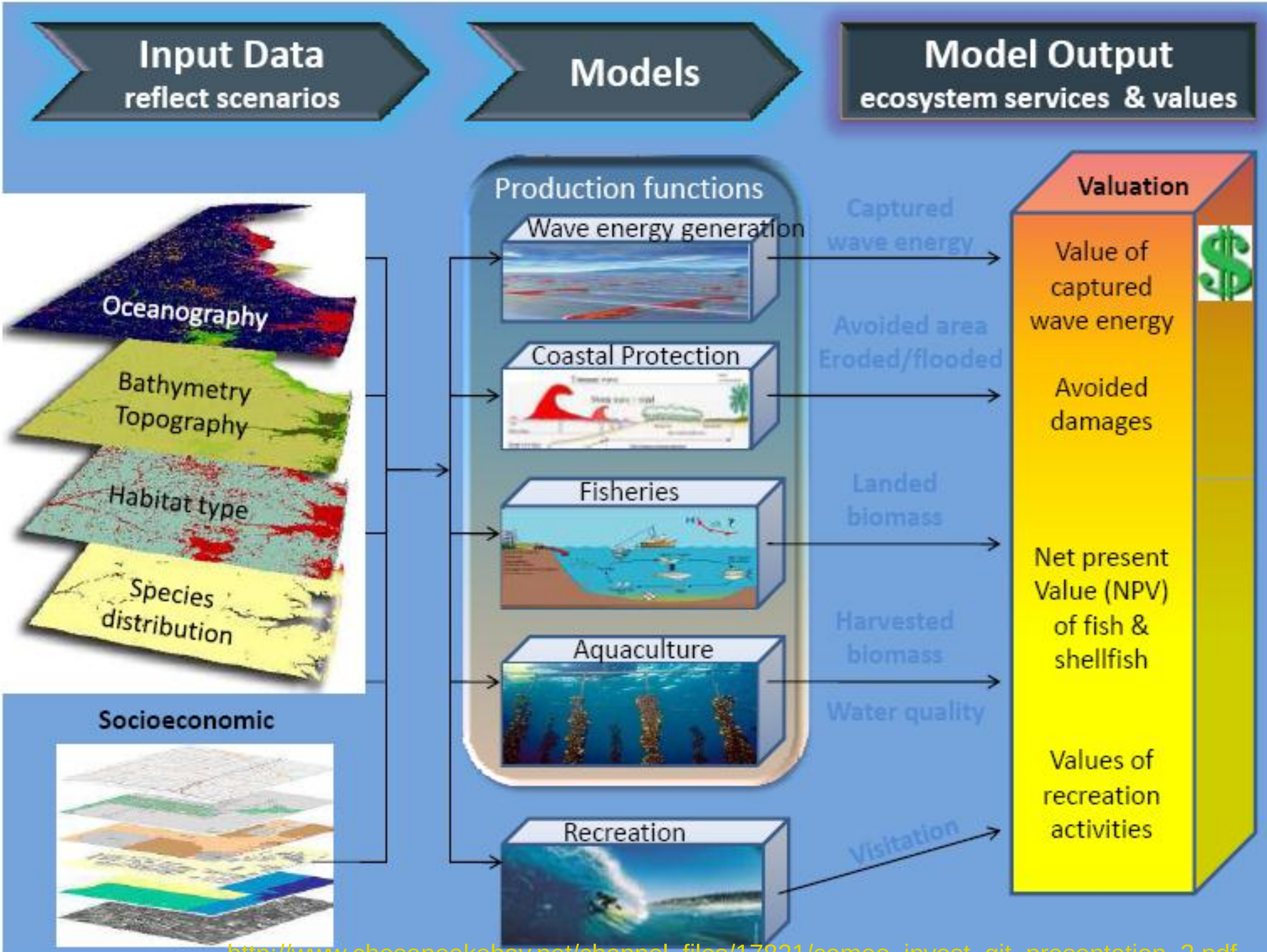
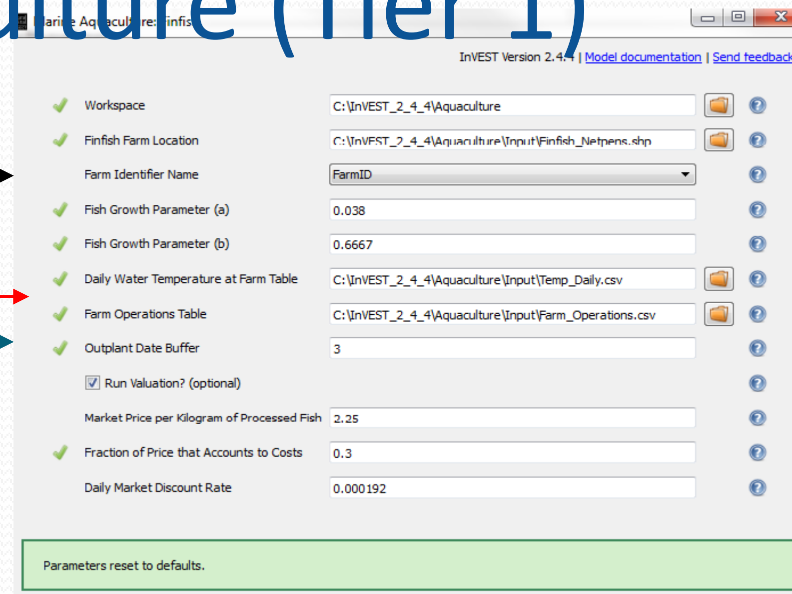


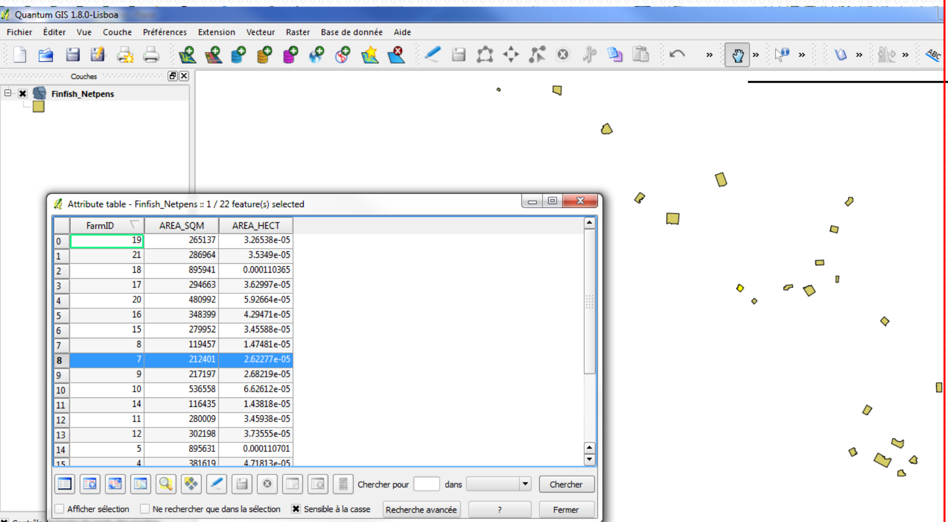
http://www.chesapeakebay.net/channel_files/17821/cameo_invest_git_presentation_2.pdf

4.Description of models: provisioning

4.1 Marine Fish Acquaculture (Tier 1)

	Step	Data requirements	Process	Output
Required	**Service**	farm operations (number of fish, feed, target harvest weight, weight at outplanting, date of outplanting, fallowing practices) farm locations temperature	estimates biomass of fish produced per farm	Biomass of fish produced per farm
Optional	**Value**	operating costs market price revenues	Calculates present value of fish produced per farm	net present value of fish produced per farm





General Operations Parameters (applies to all farms)	
Fraction of fish remaing after processing	85%
Natural mortality rate on the farm (daily)	0,000137
Duration of simulation (years)	5

Instructions:

When necessary, modify values for farm operations and/or add new farms (beginning with row "32"). Do not, however, modify the location of cells in this template.

Farm-Specific Operations Parameters

Farm #:	weight of fish at start (kg)	target weight of fish at harvest (kg)	number of fish in farm	start day for growing	Length of Fallowing period
1	0,06	5,40	600 000	60	0
2	0,06	5,40	600 000	60	0

Instructions:

1. Ensure that the below numbers in row 5 (highlighted in yellow) correspond to integer values underneath the user-specified "Farm Identifier Name" in the Finfish Farm Location GIS shapefile (model input #2). The below numbers must be unique, consecutive, positive integers, starting with a value of 1 in cell "C,5".
2. When necessary, modify daily temperature values for each farm and/or add new farms (beginning with column "Y"). Do not, however, modify the location of cells in this template.

		Farm #:																	
Day #	Day/Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	01-janv	8,447	8,447	8,947	8,649	9,082	9,014	8,311	8,311	8,311	8,379	8,514	8,514	8,514	8,514	8,379	8,379	8,379	8,447
2	02-janv	8,406	8,406	8,906	8,600	9,035	8,970	8,276	8,276	8,276	8,341	8,470	8,470	8,470	8,470	8,341	8,341	8,341	8,406
3	03-janv	8,366	8,366	8,866	8,551	8,989	8,927	8,242	8,242	8,242	8,304	8,427	8,427	8,427	8,427	8,304	8,304	8,304	8,366

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4.Description of models: provisioning
4.1 Marine Fish Acquaculture (Tier 1)

- Production and valuation functions:

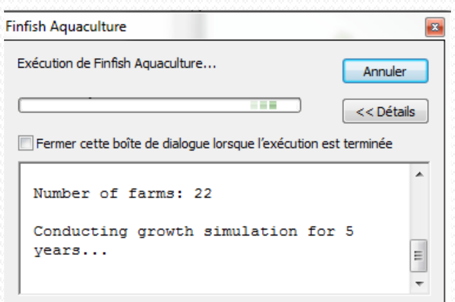
Weight W_t at time t (day), in year y, and on farm f is modeled as:

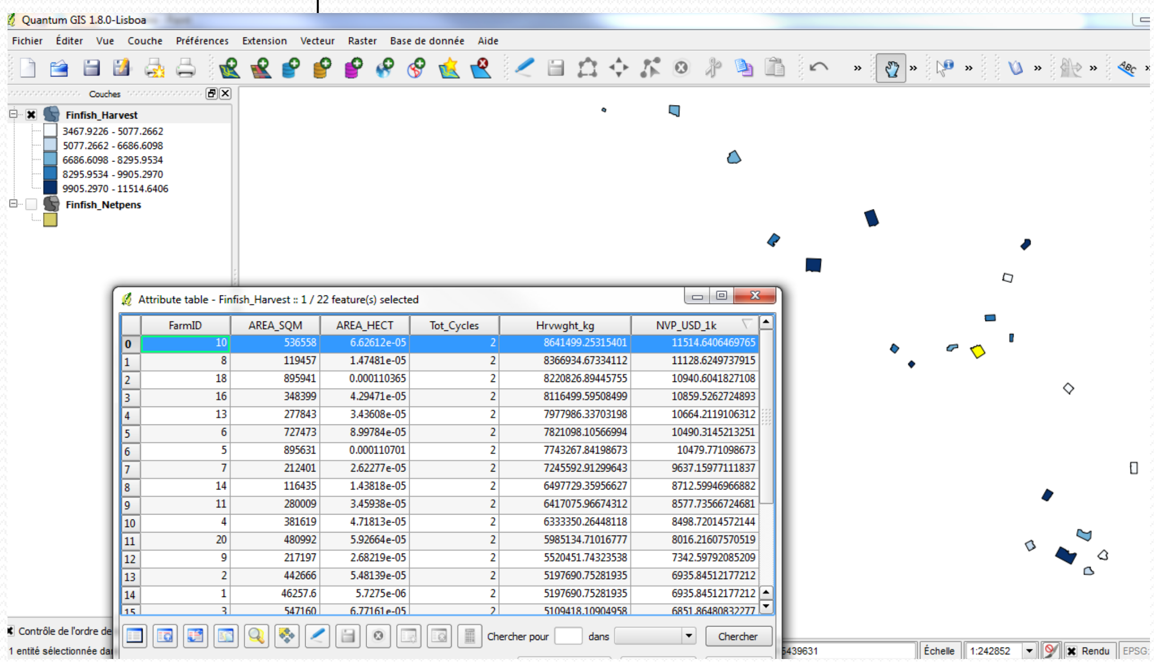
$$W_{t,y,f} = (aW^{b}_{t-1,y,f} \cdot T_{t,f}\tau) + W_{t-1,y,f}$$

The total weight of processed fish TPW on farm f in harvest cycle c:

$$TPW_{f,c} = W_{t_h,h,f} \cdot d \cdot n_f e^{-M \cdot (t_h - t_0)}$$

$$NPV_{f,c} = TPW_{f,c}[p(1-C)] \cdot \frac{1}{(1+r)^t}$$

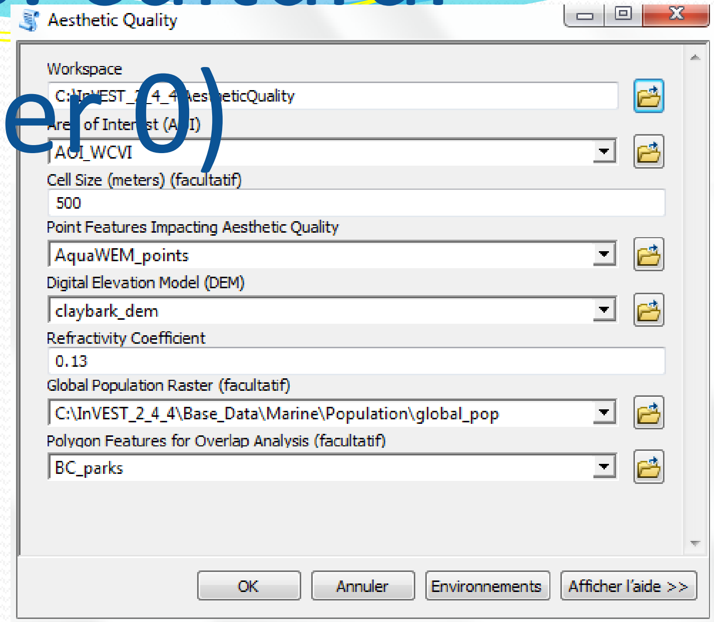




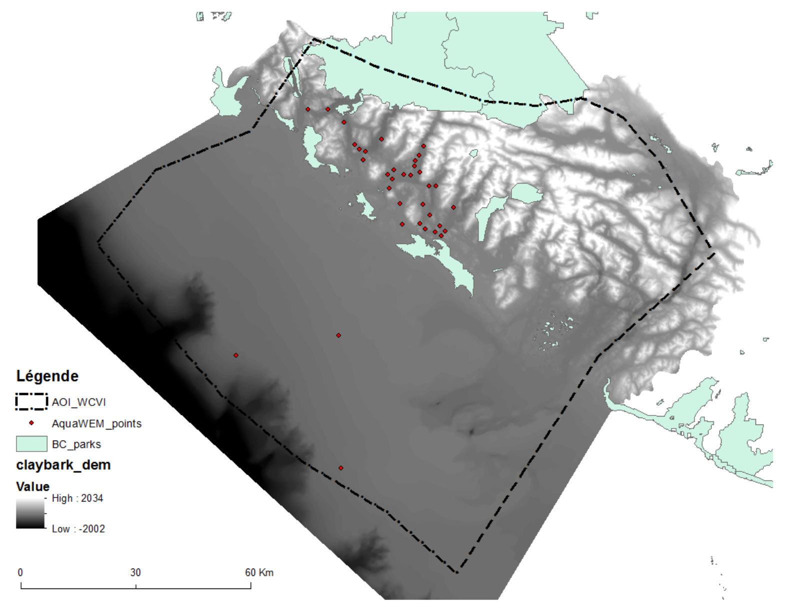
	FarmID	AREA_SQM	AREA_HECT	Tot_Cycles	Hrvwght_kg	NVP_USD_1k
0	10	536558	6.62612e-05	2	8641499.25315401	11514.6406469765
1	8	119457	1.47481e-05	2	8366934.67334112	11128.6249737915
2	18	895941	0.000110365	2	8220826.89445755	10940.6041827108
3	16	348399	4.29471e-05	2	8116499.59508499	10859.5262724893
4	13	277843	3.43608e-05	2	7977986.33703198	10664.2119106312
5	6	727473	8.99784e-05	2	7821098.10566994	10490.3145213251
6	5	895631	0.000110701	2	7743267.84198673	10479.771098673
7	7	212401	2.62277e-05	2	7245592.91299643	9637.1597711837
8	14	116435	1.43818e-05	2	6497729.35956627	8712.59946966882
9	11	280009	3.45938e-05	2	6417075.96674312	8577.73566724681
10	4	381619	4.71813e-05	2	6333350.26448118	8498.72014572144
11	20	480992	5.92664e-05	2	5985134.71016777	8016.21607570519
12	9	217197	2.68219e-05	2	5520451.74323538	7342.59792085209
13	2	442666	5.48139e-05	2	5197690.75281935	6935.84512177212
14	1	46257.6	5.7275e-06	2	5197690.75281935	6935.84512177212
15	3	547160	6.77161e-05	2	5109418.10904958	6851.86480832277

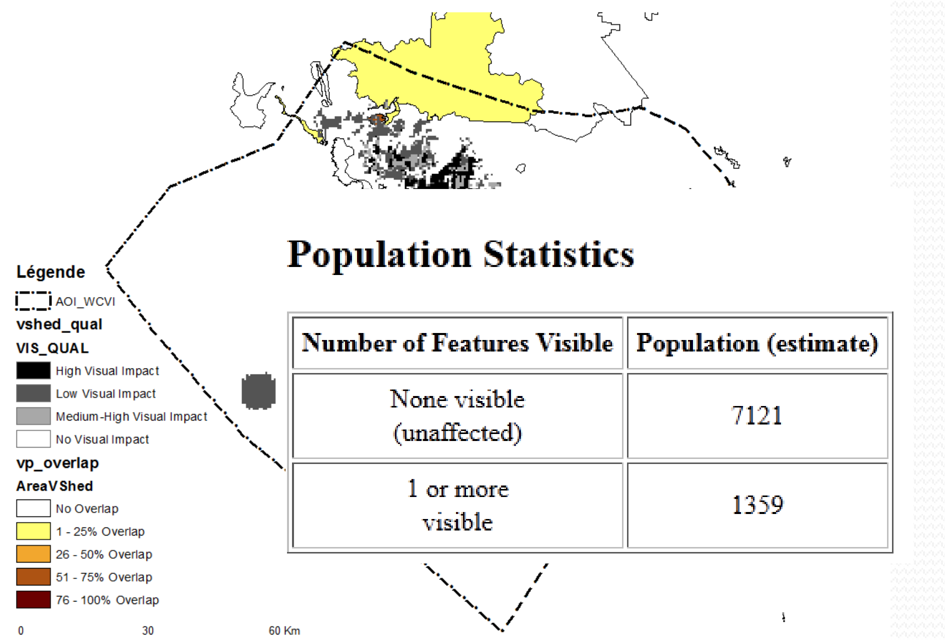
4.Description of models: cultural

4.2 Aesthetic quality (Tier 0)



	Step	Data requirements	Process	Output
Required	Supply	attributes of marine environment (location of natural desired features & development/infrastructure) attributes of shoreline environment (location of natural desired features & development/infrastructure) bathymetry topography	calculates points from which natral/desired or infrastructure can be observed	
Required	Service	access points location of public parks location of private property	calculates points from which infrastructure can be observed	number of natural (non-infrastructure or development) views per location
Optional	Value	capital costs (e.g., device, cables, etc.) operating costs revenue	Calculates present value of electricity captured per array	net present value of electricity captured from waves per array





Population Statistics

Number of Features Visible	Population (estimate)
None visible (unaffected)	7121
1 or more visible	1359

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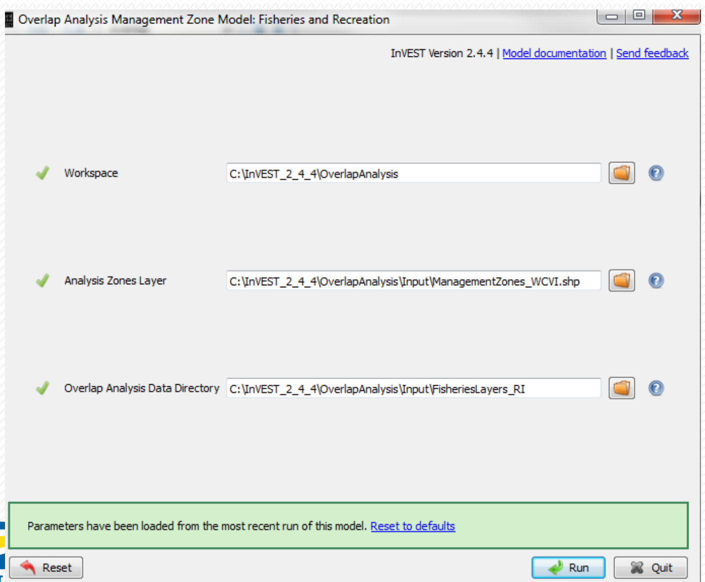
4.Description of models: cultural

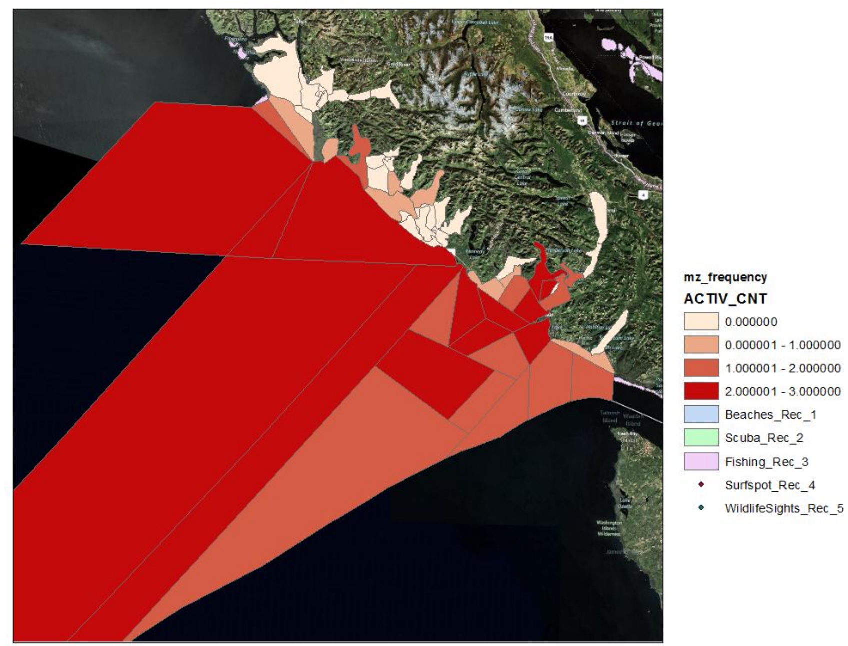
4.3 Overlap analysis (Tier 0)

Step	Data requirements		Process	Output
Required	Supply	location of natural desired features for recreation (e.g., whale sightings, mammal haul outs, kelp for SCUBA, beaches, etc.)	maps locations of recreation activities	
		location and quality of environmental conditions affecting recreation value (e.g., wave energy for beach enjoyment or wildlife viewing)		
Required	Service	location of infrastructure in support of recreation activities (e.g., campgrounds, boat launches, etc.)	calculates index of recreation importance	index of recreation importance by activity and weighted overall index
		distance between access points and activities		
		visitation rates for each location, activity		

Importance Score (IS)

$$IS_i = \sum_{i,j} U_{ij} I_j$$





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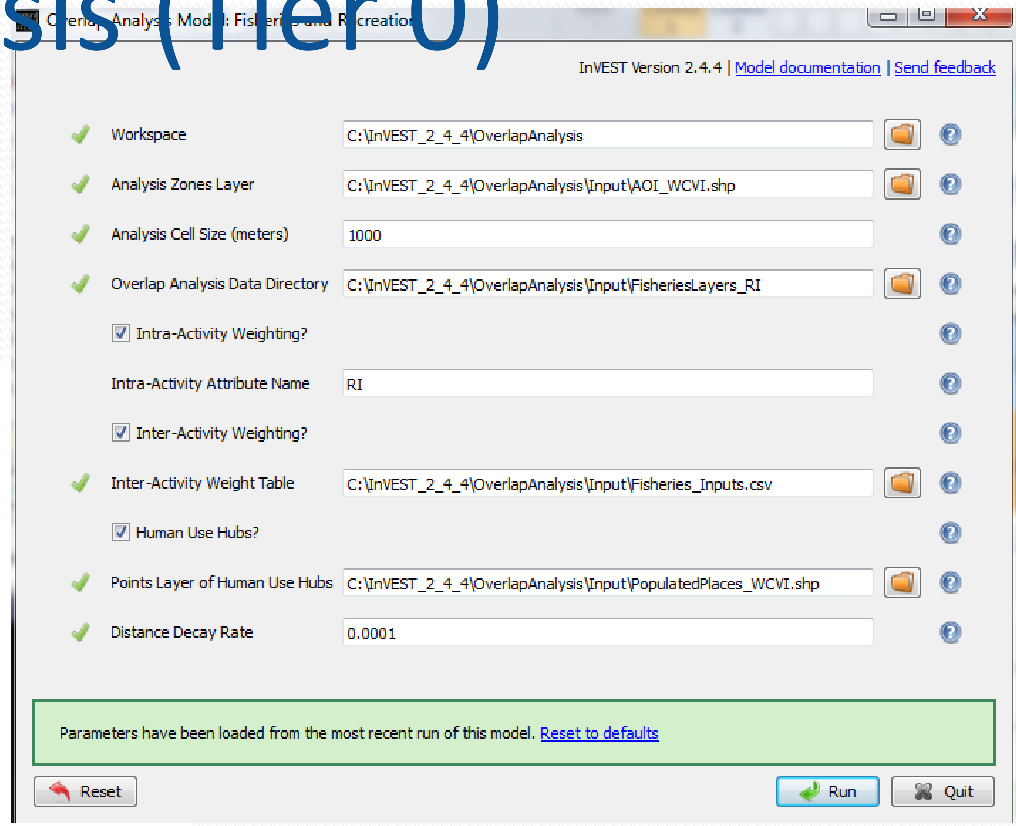
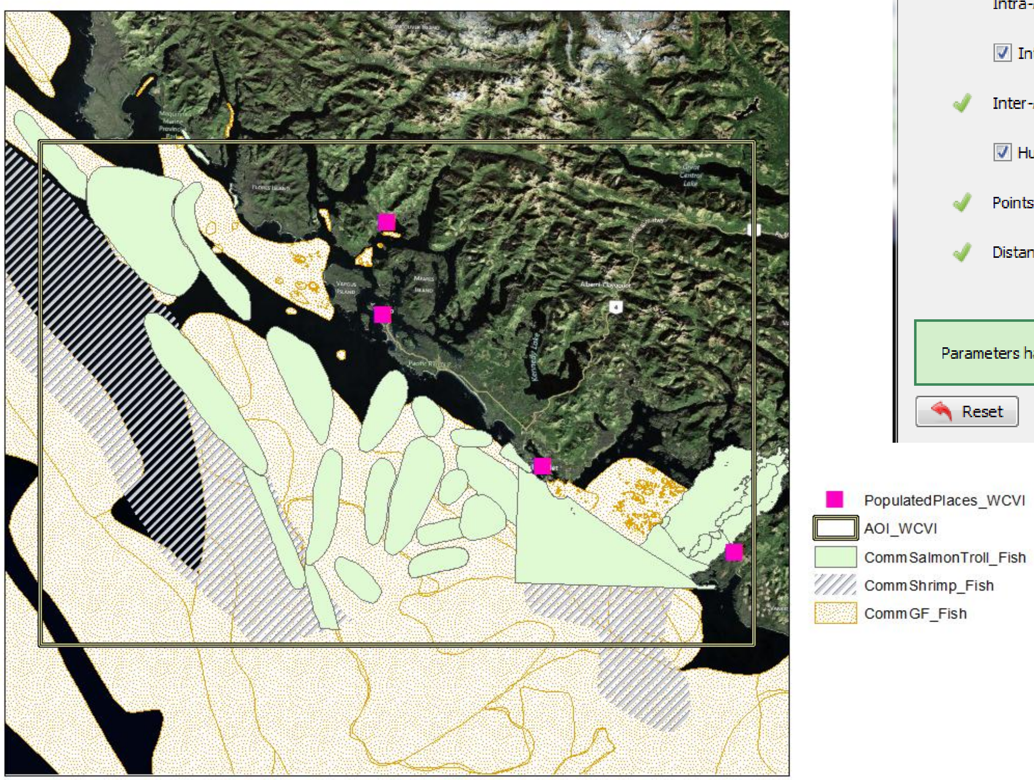
4.Description of models: cultural

4.3 Overlap analysis (Tier 0)





4.Description of models: cultural
4.3 Overlap analysis (Tier 0)

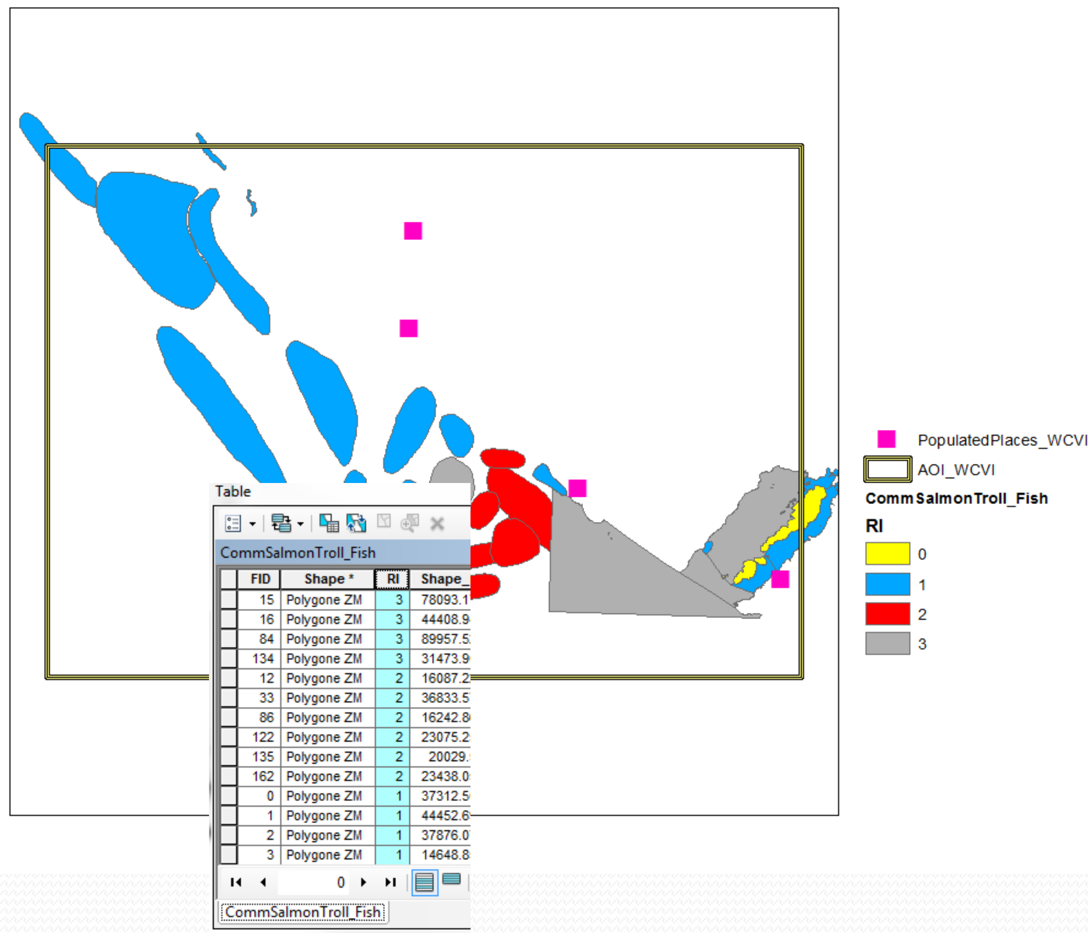
Importance Score (IS) with intra and inter activity weight:

$$IS_i = \frac{1}{n}\sum_{i,j} U_{ij} I_j$$

Inter-activity weight

	A	B
1	LIST OF HUMAN USES	OPTIONAL:
2	CommGF_Fish	2
3	CommSalmonTroll_Fish	1.5
4	CommShrimp_Fish	1.5

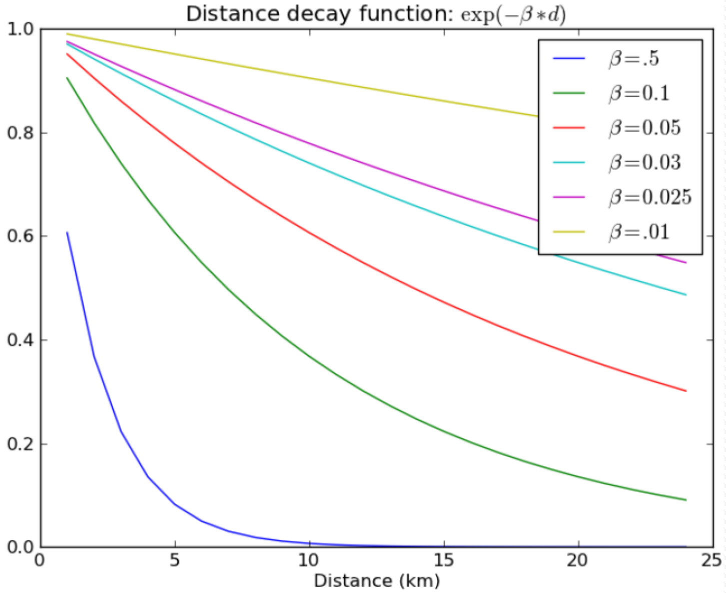
Salmon Troll Intra-activity weight

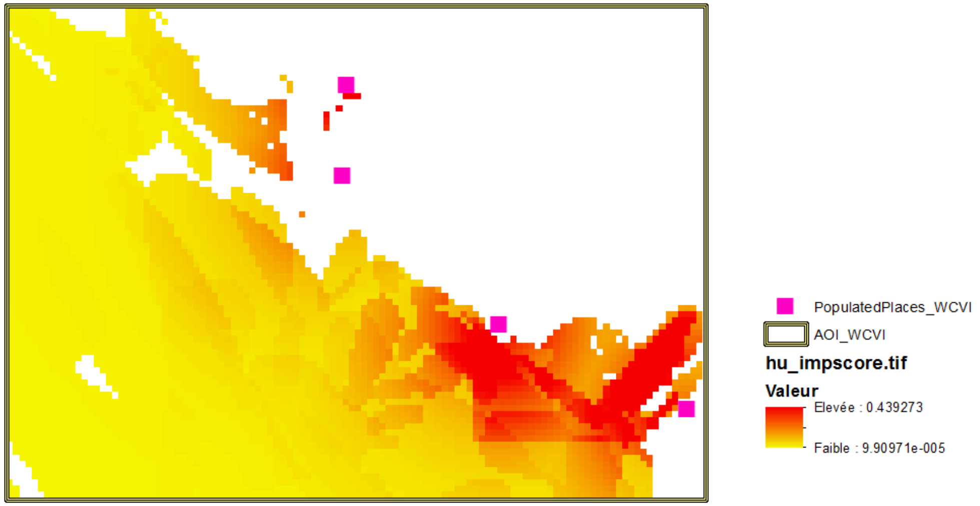


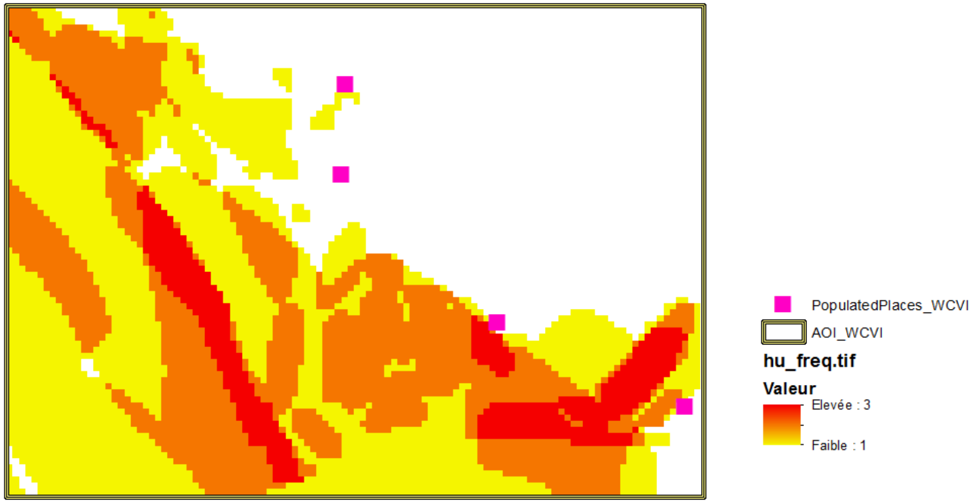
FID	Shape *	RI	Shape_
15	Polygone ZM	3	78093.1
16	Polygone ZM	3	44408.9
84	Polygone ZM	3	89957.5
134	Polygone ZM	3	31473.9
12	Polygone ZM	2	16087.2
33	Polygone ZM	2	36833.5
86	Polygone ZM	2	16242.8
122	Polygone ZM	2	23075.2
135	Polygone ZM	2	20029.
162	Polygone ZM	2	23438.0
0	Polygone ZM	1	37312.5
1	Polygone ZM	1	44452.6
2	Polygone ZM	1	37876.0
3	Polygone ZM	1	14648.8

CommSalmonTroll_Fish

4.Description of models: cultural
4.3 Overlap analysis (Tier 0)







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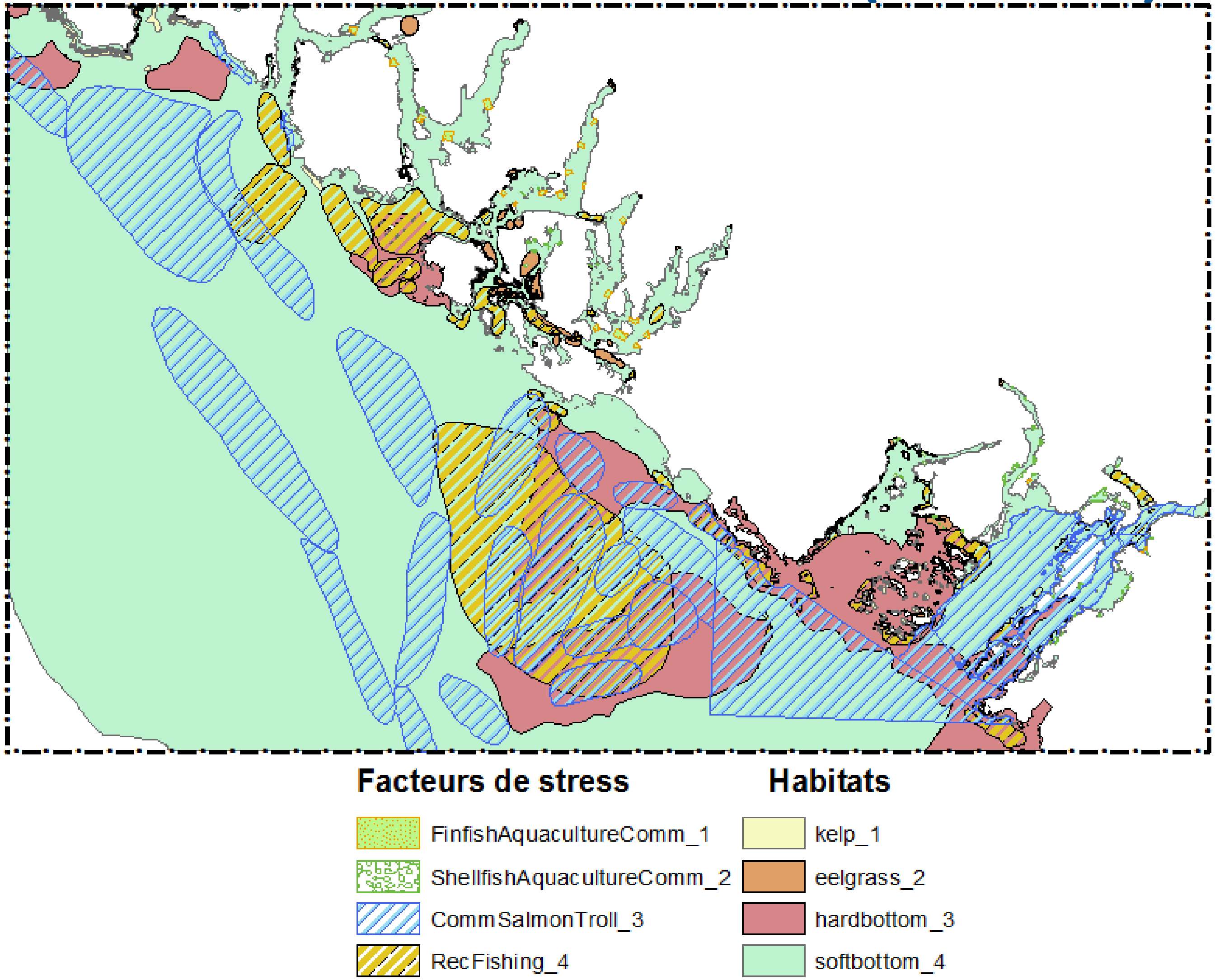
4.Description of models: supporting
4.4 Habitat Risk Assessment (Tier 0)



4.Description of models: supporting
4.4 Habitat Risk Assessment (Tier 0)

Step 1. Likelihood of exposure of the habitat to the stressor and the consequence of this exposure

$$E = \frac{\sum_{i=1}^{N} \frac{e_i}{d_i \cdot w_i}}{\sum_{i=1}^{N} \frac{1}{d_i \cdot w_i}}$$

$$C = \frac{\sum_{i=1}^{N} \frac{c_i}{d_i \cdot w_i}}{\sum_{i=1}^{N} \frac{1}{d_i \cdot w_i}}$$

Step 2. Risk value for each stressor-habitat combination

$$R_i = \sum_{j=1}^{J} R_{ij}$$

Step 3. Cumulative risk of all stressors on the habitats

$$R_{ij} = \sqrt{(E-1)^2 + (C-1)^2}$$

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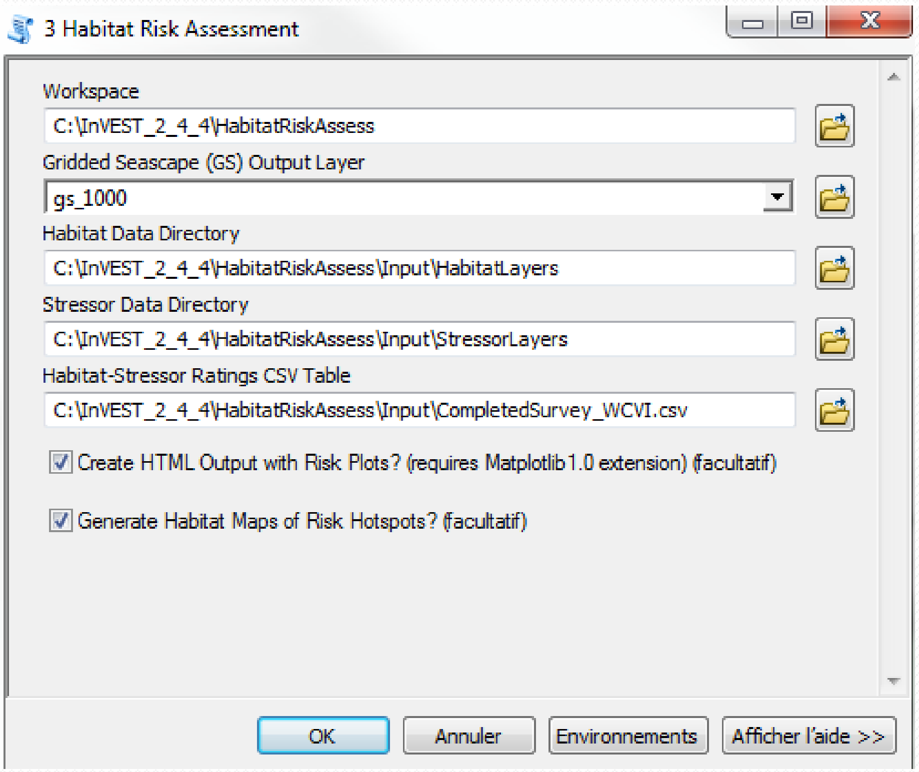
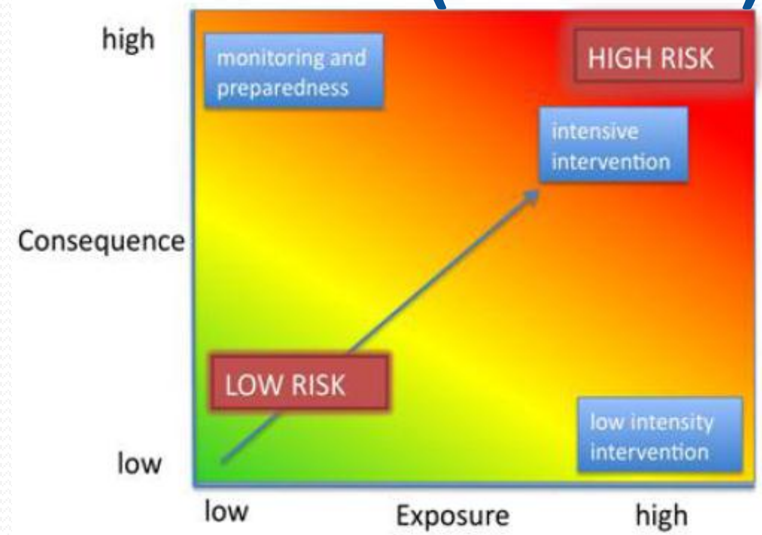
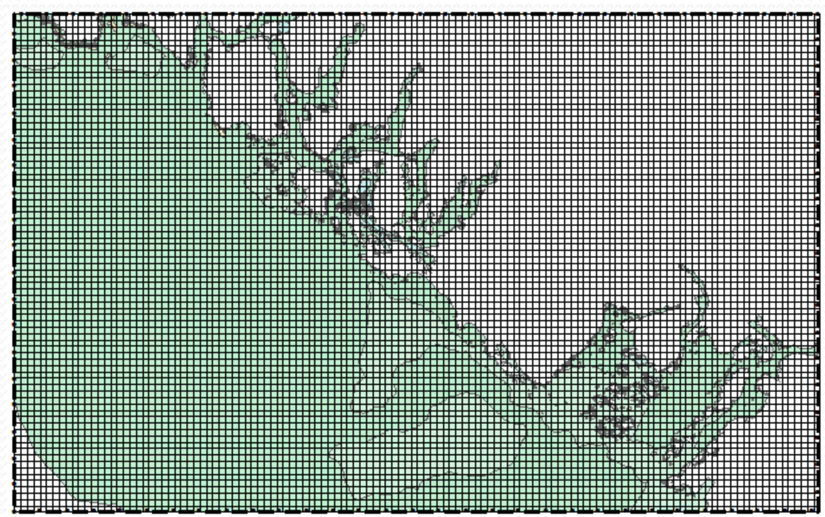
4.Description of models: supporting

4.4 Habitat Risk Assessment (Tier 0)







4.Description of models: supporting

4.4 Habitat Risk Assessment (Tier 0)

Habitat ID	Habitat Name	Habitat DQ	Mortality	Mortality DQ	Recruitment	Recruitment [	Connectivity	Connectivity [	Regeneration	Regeneration DQ
0	kelp	1	1	0	2	0	2	0	1	0
1	eelgrass	1	1	0	1	0	1	0	1	0
2	hard bottom	2	0	0	0	0	0	0	3	0
3	soft bottom	2	0	0	0	0	0	0	1	0

4

Stressor ID	Stressor Nam	Stressor DQ	Intensity	Intensity DQ	Management	Managment [	Buffer
0	Finfish Aquac	1	3	0	3	0	300
1	Shellfish Aqu	1	2	0	2	0	250
2	Comm Salmo	2	3	0	3	0	150
3	Rec Fishing	2	2	0	2	0	100

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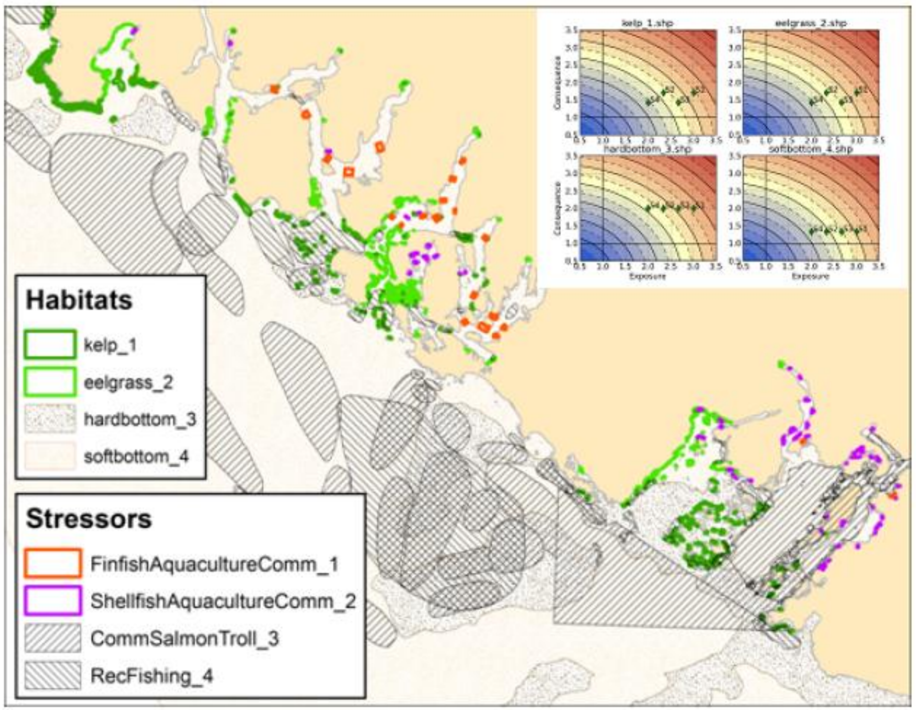
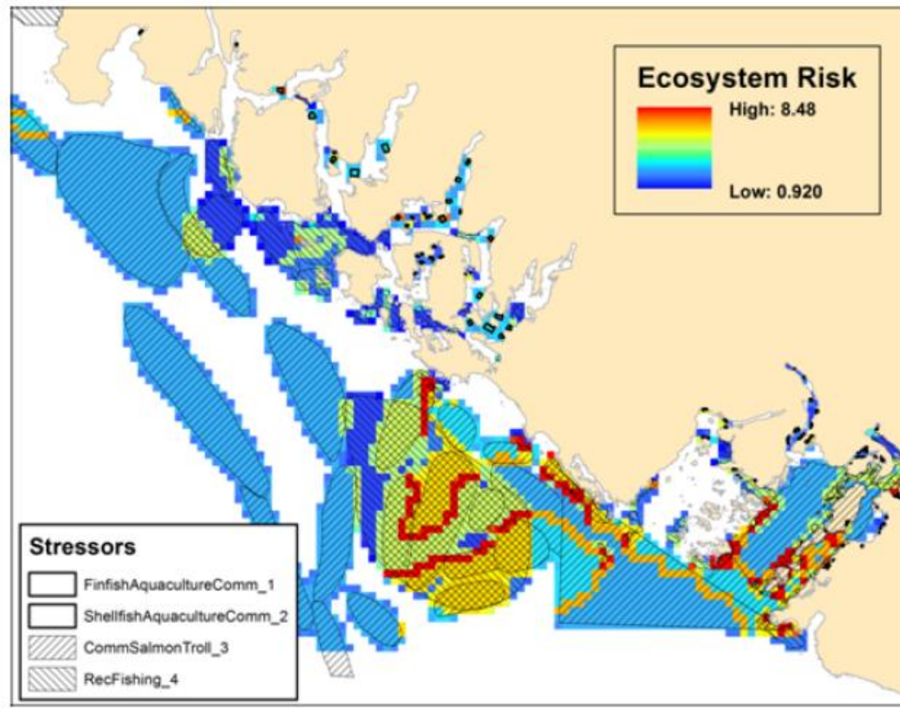
Habitat ID	Habitat Name	Stressor ID	Stressor Nam	Area Change	Area Change	Structure Cha	Structure Cha	Disturbance F	Disturbance F	Temporal Ove	Temporal Overlap DQ
0	kelp	0	Finfish Aquac	2	1	2	1	2	1	3	1
0	kelp	1	Shellfish Aqu	2	1	2	1	2	1	3	1
0	kelp	2	Comm Salmo	1	1	1	1	2	1	2	1
0	kelp	3	Rec Fishing	1	1	1	1	2	1	2	1
1	eelgrass	0	Finfish Aquac	3	1	3	1	2	1	3	1
1	eelgrass	1	Shellfish Aqu	3	1	3	1	2	1	3	1
1	eelgrass	2	Comm Salmo	2	1	2	1	2	1	2	1
1	eelgrass	3	Rec Fishing	2	1	2	1	2	1	2	1
2	hard bottom	0	Finfish Aquac	0	0	1	0	2	0	3	1
2	hard bottom	1	Shellfish Aqu	0	0	1	0	2	0	3	1
2	hard bottom	2	Comm Salmo	0	0	1	0	2	0	2	1
2	hard bottom	3	Rec Fishing	0	0	1	0	2	0	2	1
3	soft bottom	0	Finfish Aquac	0	0	1	0	2	0	3	1
3	soft bottom	1	Shellfish Aqu	0	0	1	0	2	0	3	1
3	soft bottom	2	Comm Salmo	0	0	1	0	2	0	2	1
3	soft bottom	3	Rec Fishing	0	0	1	0	2	0	2	1

4.Description of models: supporting
4.4 Habitat Risk Assessment (Tier 0)





4.Description of models: supporting
4.5 Water quality (Tier 0)

- Considers the physical transport and biogeochemical processes for simulating water state variables (e.g., contaminants, pollutants) in response to various management decisions under consideration by users.

- Advection-diffusion model

$$E^T\left(\frac{\partial^2 C}{\partial x^2}+\frac{\partial^2 C}{\partial y^2}\right)-\left(U\frac{\partial C}{\partial x}+V\frac{\partial C}{\partial y}\right)+S=0$$

Where

- x and y east and north coordinates, respectively
- C tidal averaged concentration of a water quality state variable
- U and V advective velocities (i.e., Eulerian residual current) in x and y directions, respectively
- E^T tidal dispersion coefficient
- S term to account for sources and sinks of pollutant

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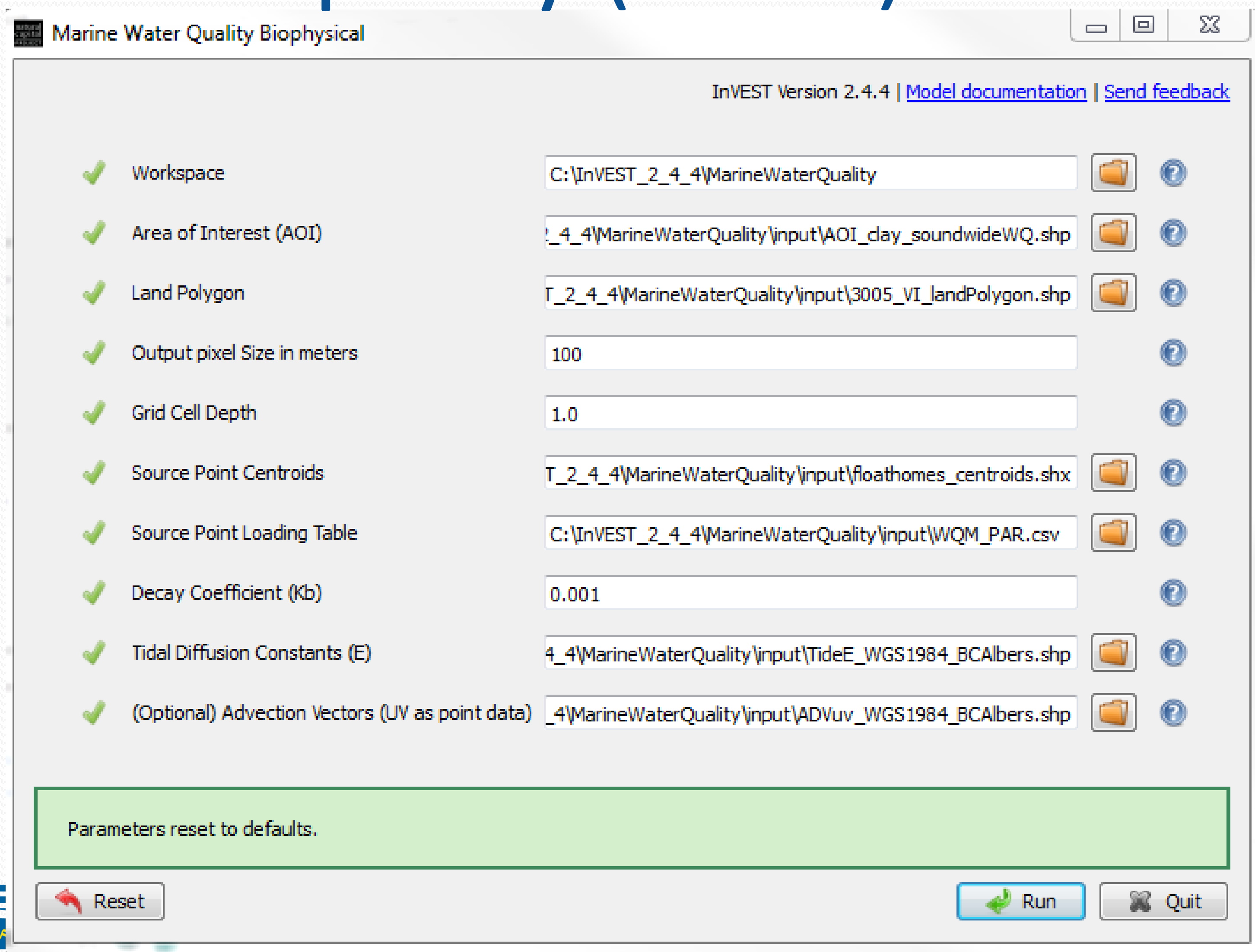
4.Description of models: supporting

4.5 Water quality (Tier 0)



4.Description of models: supporting
4.5 Water quality (Tier 0)

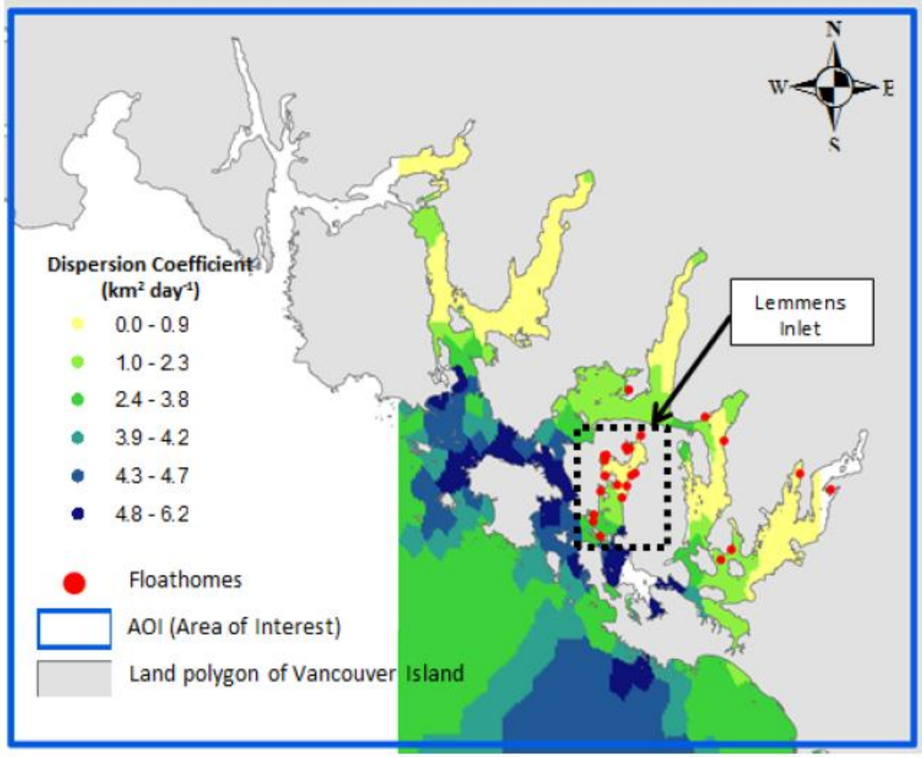


Figure 1. A map of Clayoquot Sound, BC, Canada showing a status quo arrangement of floathomes (red dots). The dotted box indicates Lemmens Inlet, the region of interest for potentially rearranging floathomes and/or exploring the effects of treating wastes. Background colors indicate tidal dispersion coefficients for the region, a key model input.

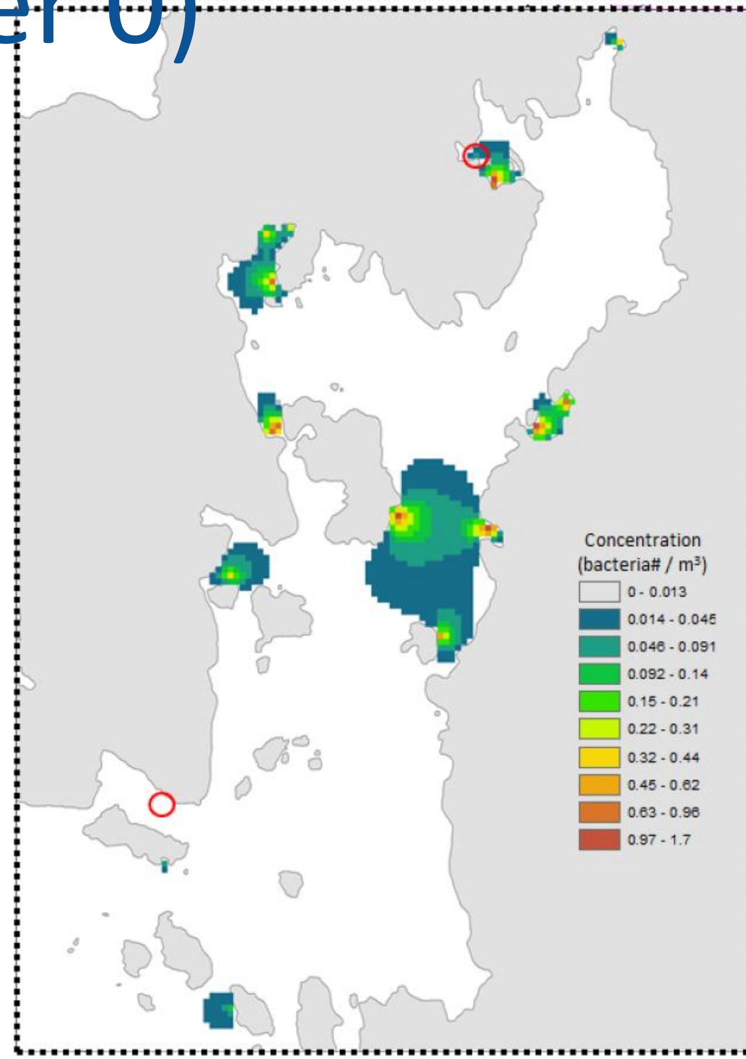


Figure 3. Map of modeled concentration of fecal coliform bacteria in Lemmens Inlet. Red circles indicate treated wastes. The results are for demonstration purposes only.

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4.Description of models: regulating
4.6 Coastal vulnerability (Tier 0)

$$P = \frac{1}{2} H^2 T$$

$$VI = \sqrt{\frac{R_{Geomorphology} R_{Relief} R_{Habitats} R_{SLR} R_{WindExposure} R_{WaveExposure} R_{Surge}}{Count_{Var}}}$$

$$EI = \sqrt{\frac{R_{Geomorphology} R_{Habitats} R_{WaveExposure}}{3}}$$

$$\begin{cases} H = \widetilde{H}_{\infty} \left[\tanh\left(0.343 \widetilde{d}^{1.14}\right) \tanh\left(\frac{2.14 \cdot 10^{-4} \widetilde{F}^{0.79}}{\tanh(0.343 \widetilde{d}^{1.14})} \right) \right]^{0.572} \\ T = \widetilde{T}_{\infty} \left[\tanh\left(0.1 \widetilde{d}^{2.01}\right) \tanh\left(\frac{2.77 \cdot 10^{-7} \widetilde{F}^{1.45}}{\tanh(0.1 \widetilde{d}^{2.01})} \right) \right]^{0.187} \end{cases}$$

$$E_w^l = \sum_{k=1}^{16} P_k^l O_k^l$$

$$R_{Hab} = 4.8 - 0.5 \sqrt{1.5 (\max_{k=1}^{N} (5 - R_k))^2 + (\sum_{k=1}^{N} (5 - R_k)^2 - (\max_{k=1}^{N} (5 - R_k))^2}$$

$$REI = \sum^{16} U_n P_n F_n$$

$$E_w = \max(E_w^o, E_w^l)$$

$$E_w^o = \sum_{k=1}^{16} H[F_k] P_k^o$$

$$H[F_k] = \begin{cases} 0 & \text{if } F_k < 50km \\ 1 & \text{if } F_k \geq 50km \end{cases}$$

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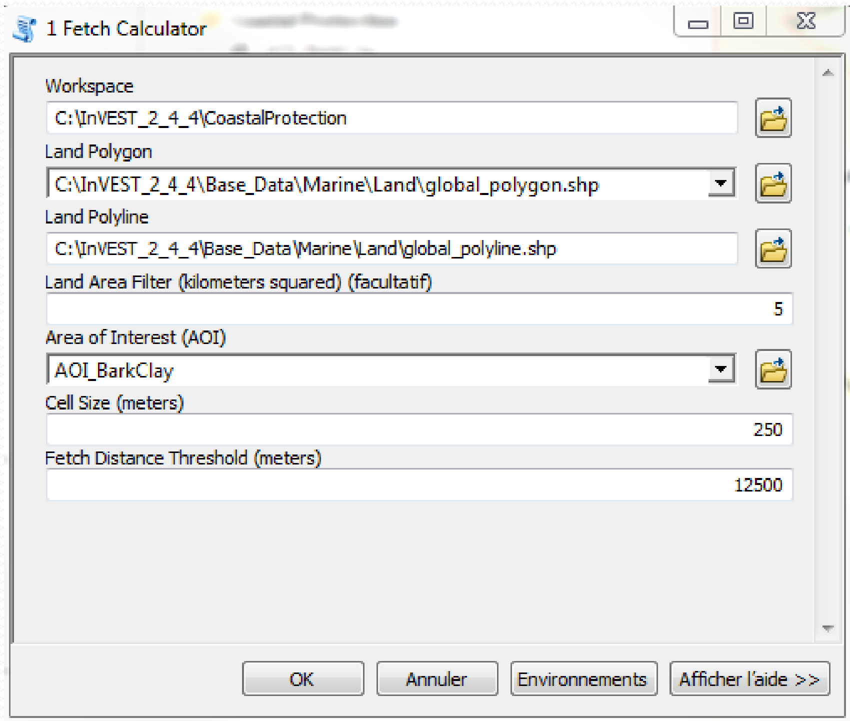
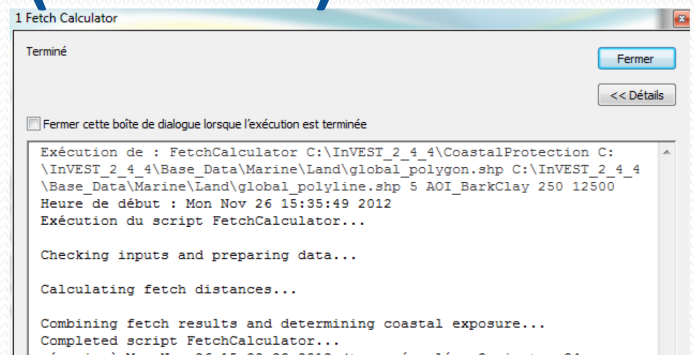
Rank Variable	Very Low 1	Low 2	Moderate 3	High 4	Very High 5
Geomorphology	Rocky; high cliffs; fjord; fiard, seawalls	Medium cliff; indented coast, bulkheads and small seawalls	Low cliff; glacial drift; alluvial plain, revetments, rip-rap walls	Cobble beach; estuary; lagoon; bluff	Barrier beach; sand beach; mud flat; delta
Relief	<=20th Percentile	<=40th Percentile	<=60th Percentile	<=80th Percentile	>80th Percentile
Natural Habitats	Coral reef; mangrove; coastal forest	High dune; marsh	Low dune	Seagrass; kelp	No habitat
Sea Level Change	Net decrease		-1 to +1		Net rise
Wind Exposure	<=20th Percentile	<=40th Percentile	<=60th Percentile	<=80th Percentile	>80th Percentile
Wave Exposure	<=20th Percentile	<=40th Percentile	<=60th Percentile	<=80th Percentile	>80th Percentile
Surge Potential	<=20th Percentile	<=40th Percentile	<=60th Percentile	<=80th Percentile	>80th Percentile

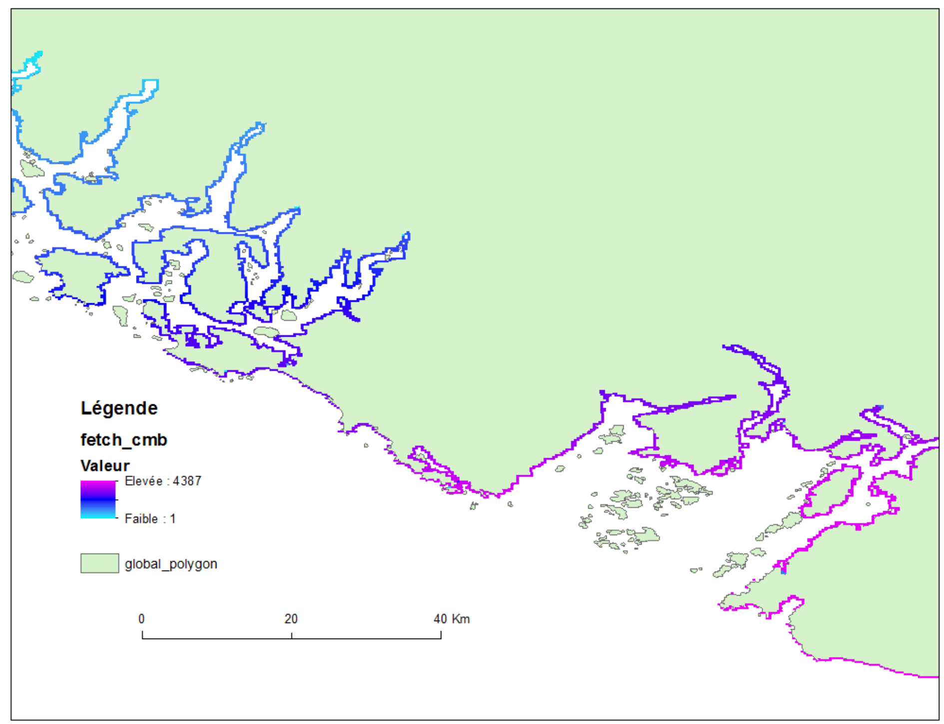
Table 4.1: List of Bio-Geophysical Variables and Ranking System for Coastal Exposure.

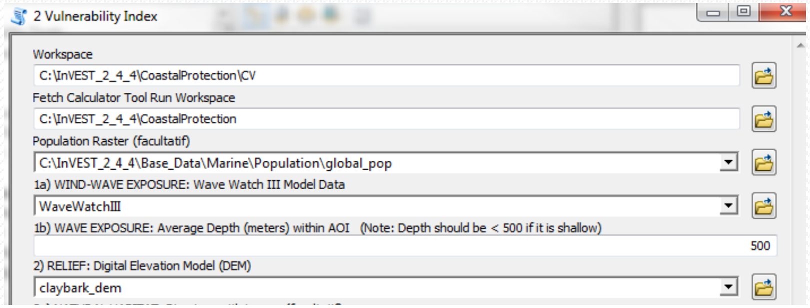
4.Description of models: regulating

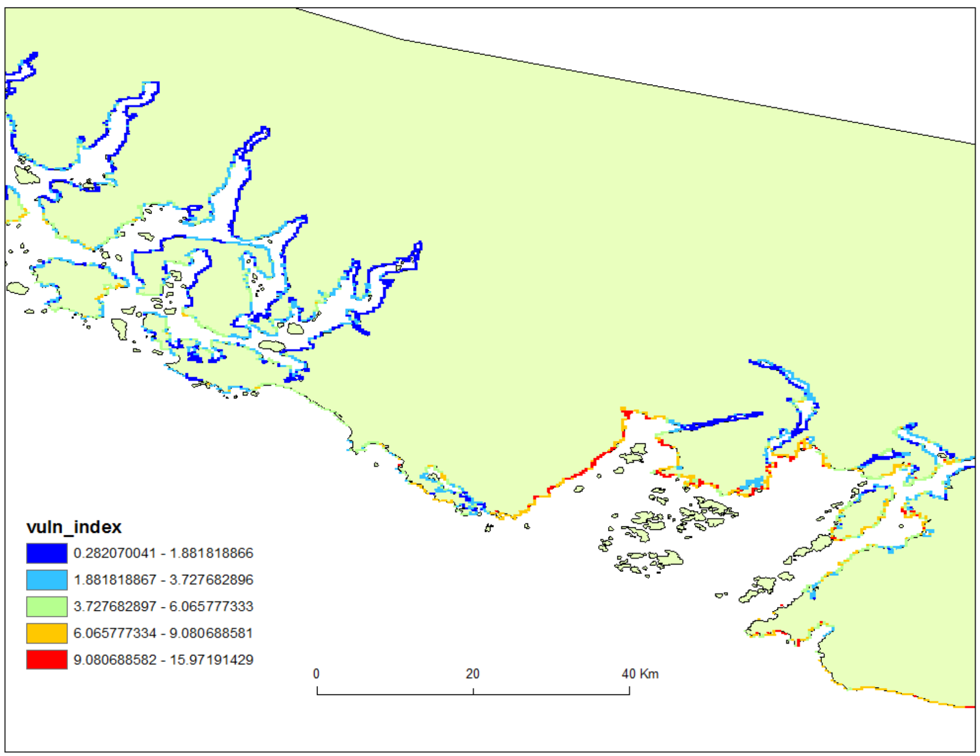
4.6 Coastal vulnerability (Tier 0)

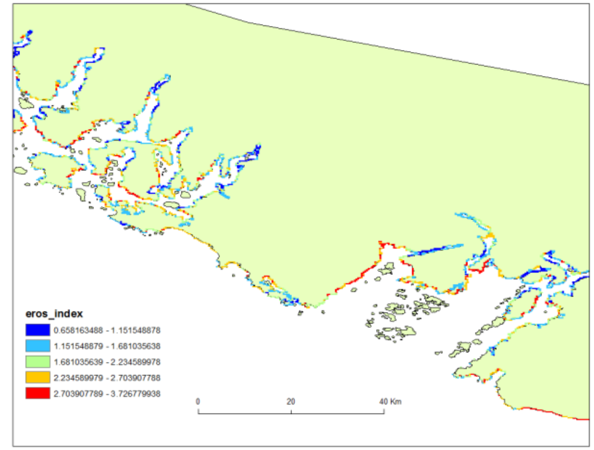


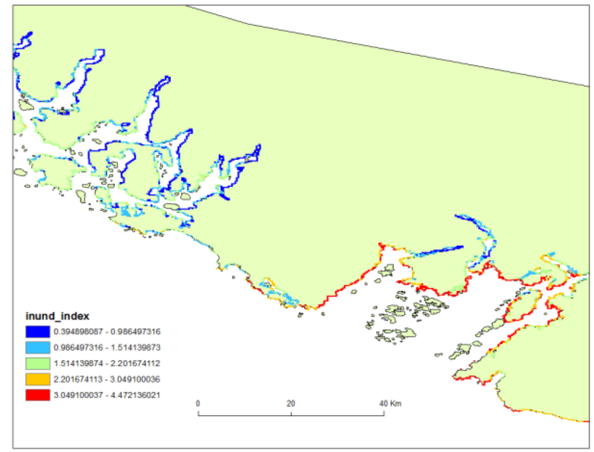


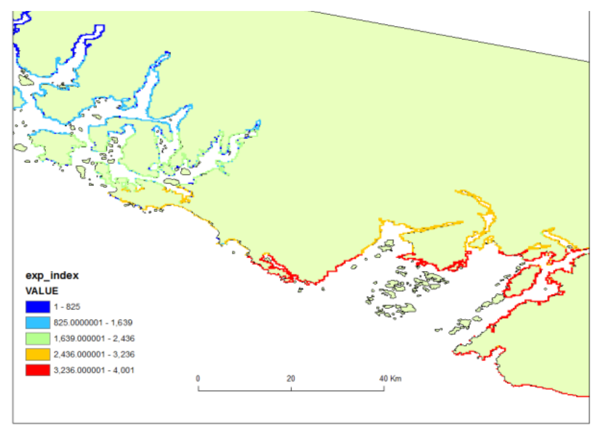












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5. Case study

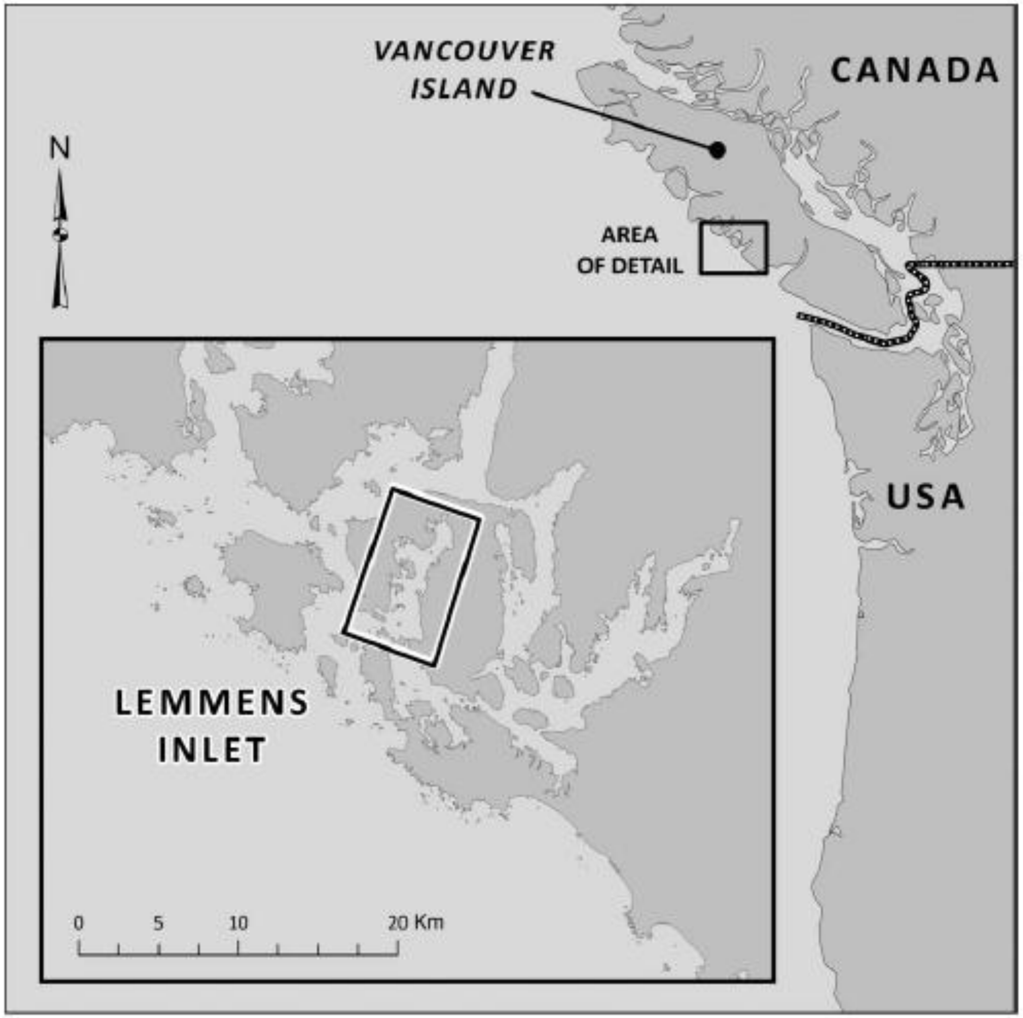
Application of marine InVEST to WCVI (Guerry et al, 2012)

Problem

- Creation of a MSP

Ecosystem services

- Food, water quality, habitat and recreation



5. Case study

Methods

- Interviews with stakeholders
- **3 management scénarios**:

i) Industrial expansion (more shellfish acquaculture, more floating homes)

ii) Conservation (more usage restrictions)

iii) Baseline

5. Case study

- **Methods**

Production:

- **Shellfish acquaculture**

Cultural:

- Recreation (kayak and floating homes)

Supporting services

- HRA
- Water quality

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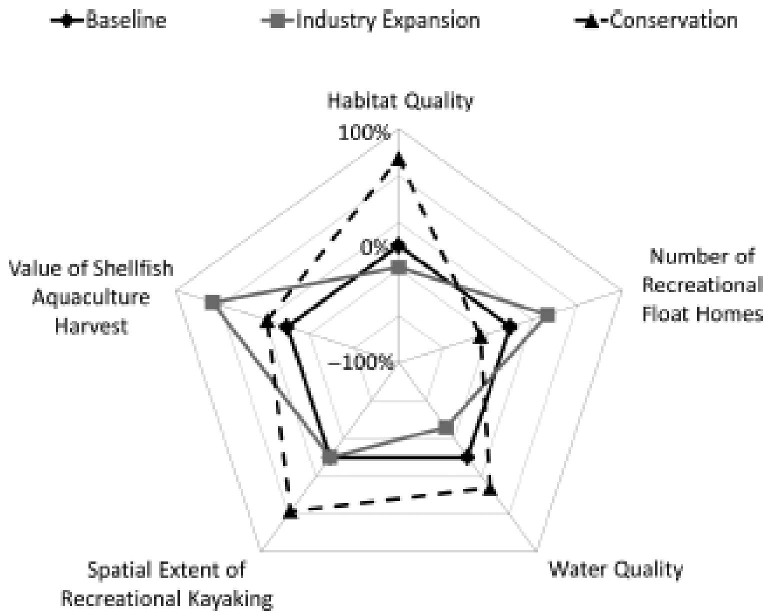
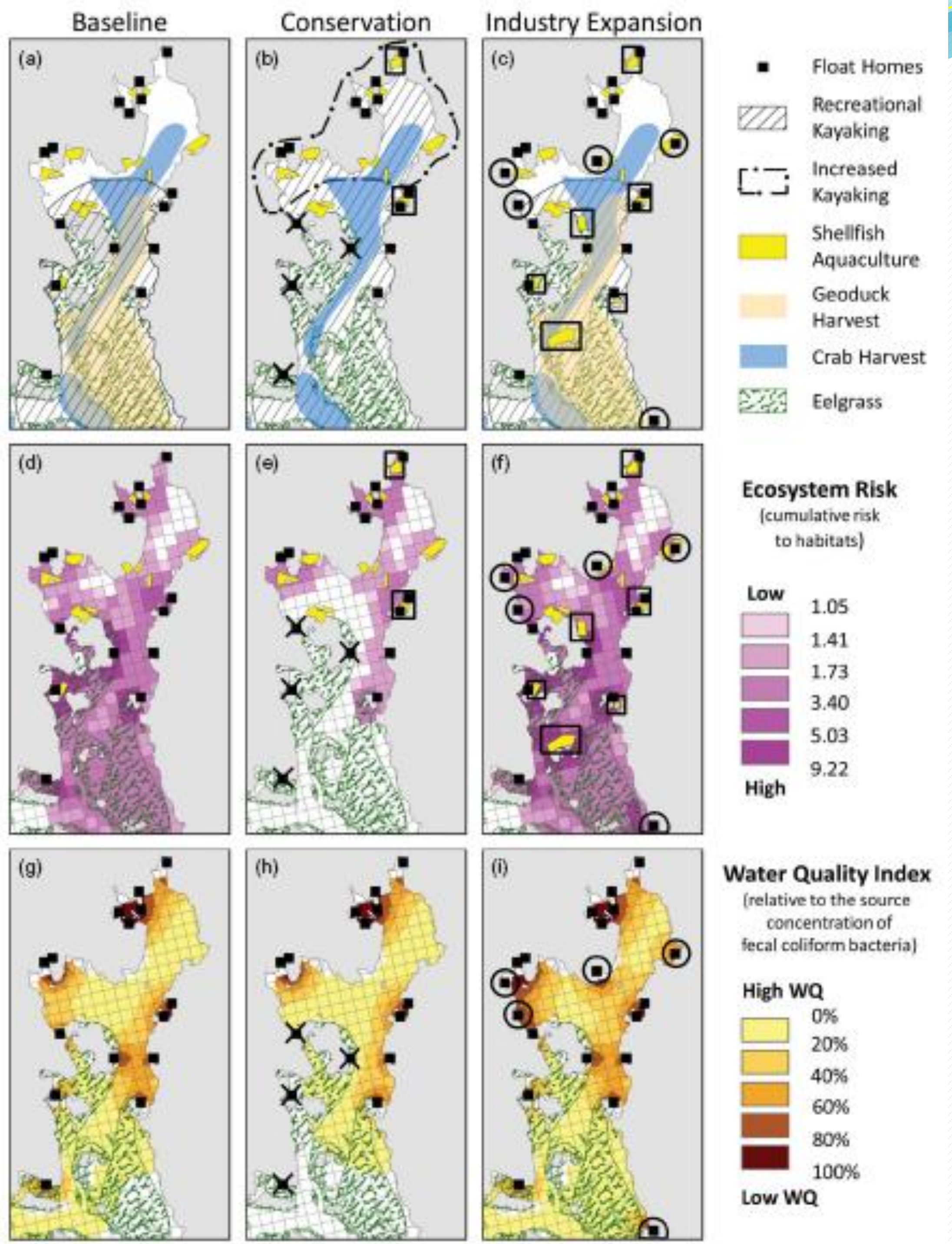
5. Case study

- **Results**





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5. Case study

Results

Conservation scenario

- Kayak route increase extension (57%)
- 98.998 USD (+18%) shellfish acquaculture
- Decrease in the number of floating homes (-4)
- Improovement of HRA (-75%)
- Increase of water quality (32%)

Expansion scenario

- Shellfish farms (+5). Increase of 367.726 USD (67%)
- Location of shellfish farms have low impact in WQ
- More floating homes (+5) decrease WQ
- Increase in HRA (18%)
- No impact in kayak activity

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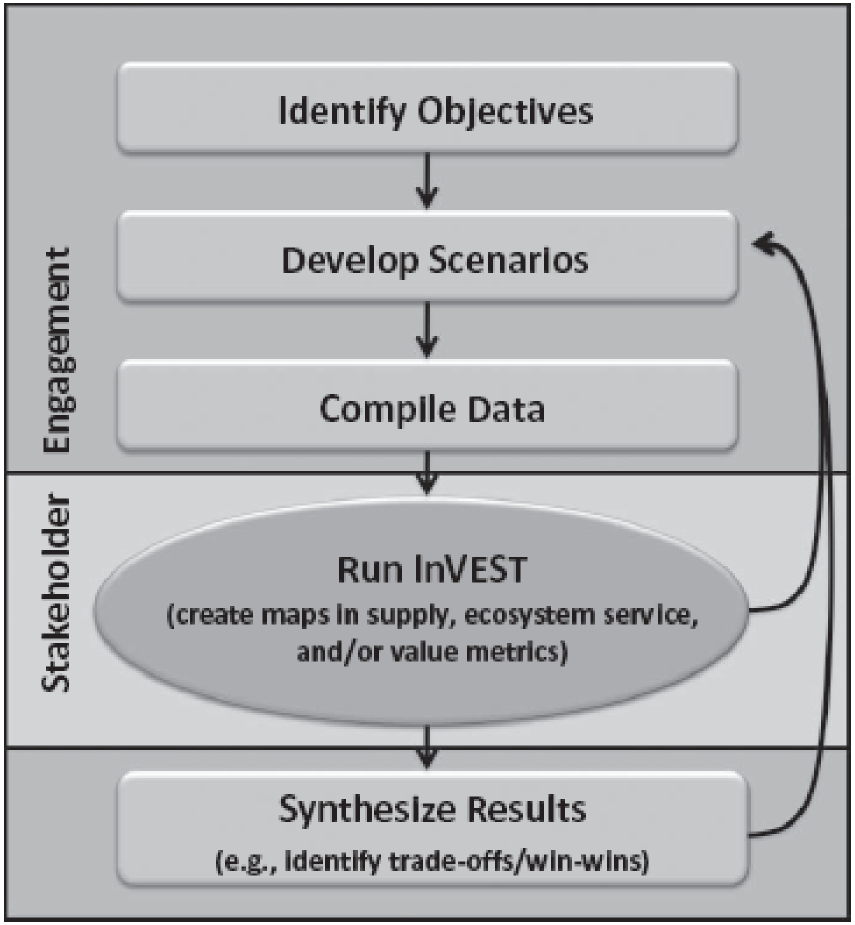
5. Discussion

- InVEST is useful for MSP
  - Clarifies objectives
  - Makes the tradeoffs explicit
  - Provides metrics for comparing alternatives
  - Facilitates an interactive and iterative engagement
- New models are planned
- Scenario generator

5. Discussion

IMPORTANT QUESTIONS

1. What are the relevant SE?
2. Which level of complexity is necessary for modelling?
3. Data?
4. Which scenarios?



(Guerry et al 2012)

« InVEST ins’t a crystal ball that is going to tell us what to do…but it will help us to compare the options» (Anne Guerry, 2012)

Thanks!