Model Name: Eastern Oyster Habitat Suitability Index

Functional Area: Ecosystem Services / Upper Trophic Level

Model Proponents: Coastal Protection and Restoration Authority

Model Developer(s): Thomas M. Soniat, University of New Orleans

Please note this is a working-draft document currently undergoing review and revision. The final version will be posted in March 2012 along with the final version of the 2012 Coastal Master Plan.

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1. *Background*

a. Purpose of Model

Coastal protection and restoration projects such as levees, marsh creation, ridge building, and sediment and river diversions potentially impact oyster populations and oyster habitat. The purpose of the model is to assess the impacts of coastal protection and restoration projects on oyster habitat. The targeted users of the model are state managers responsible for coastal protection and restoration and those charged with the protection of oyster habitat. The model is also useful to federal government managers, particularly those of the Army Corps of Engineers, Fish and Wildlife Service and the Geological Survey. The Oyster Habitat Suitability Index Model (Oyster HSI) provides a quantitative, objective tool for the resolution of conflicts arising from coastal restoration and protection projects.

b. Model Description and Depiction

The overarching assumption of the Oyster HSI is that oyster habitat quality can be described as suitable salinity over suitable substrate. Suitable salinity is resolved into three salinity-based variables, which treat different aspects of the oyster's dependency on salinity. A higher optimal salinity for spawning and set than for survival of adults is described as mean salinity during the spawning season, an annual mean salinity designates an expected range over which oysters exist as well as an optimum range over which they thrive, and a minimum annual salinity defines the impacts of killing floods. Suitable cultch is expressed as the percentage of the bottom covered with hard substrate (e.g., oyster shell). A percent land variable restricts oysters to aquatic model grid cells and includes or excludes them from others as land is lost or built. A value for each variable is assigned a corresponding dimensionless Suitability Index (SI) value which varies from 0 (unsuitable) to 1.0 (optimal). The Oyster HSI, which likewise varies from 0 to 1.0, is calculated as a geometric mean of the SI values; thus, if any component SI is 0 (unsuitable), HSI is 0 (poor quality habitat). The model supports the calculation of an HSI with the static percent cultch (PC) layer (described in 1.d. below) or with the static PC layer plus an artificially set cultch percentage coast wide. An HSI which includes the static cultch layer alone is an evaluation of habitat quality under present cultch conditions; whereas, an HSI with the static cultch layer plus cultch artificially set to a certain percentage evaluates potential quality habitat if the salinity variables are favorable.

Unlike the model of Cake (1983), the present Oyster HSI includes only one component index. It combines requirements of larvae (mean salinity during the spawning season, suitable cultch for setting of larvae) and those of adults (annual mean salinity, minimum salinity for adult survival and suitable cultch as it provides a substrate firmness capable of supporting adult oysters). Thus, the HSI is calculated as a single equation, as described in Section 2.

The model was constrained by the data available to support it and was constructed to be as simple as possible while remaining descriptive of oyster habitat quality. The Eco-Hydrology model provided monthly mean salinities for large polygons throughout the coast (See Appendix D-1 Eco-Hydrology Model Report). No data were provided on historical salinity, oyster stock, and oyster disease and predators and limited data were available on bottom type. It was therefore impossible to construct models using all of the variables of Cake (1982) and Soniat and Brody (1988).

c. Contribution to Planning Effort

The model has potential application to assess the effect of any protection or restoration project which modifies salinity or substrate on the suitability of oyster habitat. Example projects include river diversions or hydrological modifications which alter salinity, land building which replaces oyster bottoms with marshes or ridges, and sediment additions which cover suitable cultch.

d. Description of Input Data

Salinity values are derived from the spatially-referenced data in polygons provided by the Eco-Hydrology model. However, these polygons were considered too large to provide adequate salinity resolution for the Oyster HSI, and it was determined that greater spatial resolution was required. To further resolve salinities, the Eco-Hydrology polygon map was overlaid by a 500 x 500m grid; linear interpolations were made across salinity gradients; and each grid was populated with a monthly salinity value. These interpolated monthly values for each 500 x 500m grid were used to derive values for the salinity-based variables – mean annual salinity, minimum monthly salinity, and mean salinity during the spawning season.

No complete data set exists from which PC values could be generated; instead, an approach based upon a hierarchy of data quality and surrogates of percent coverage was used. A 500 x 500m grid overlay of the Louisiana coast was created and populated with PC values. PC is thus the percentage of the 500 x 500m grid that is covered with hard bottom. The highest quality data (first level in the hierarchy) are from reefs on public grounds mapped for the Louisiana Department of Wildlife and Fisheries (LDWF) by side scan surveys. Overlays of mapped reefs fall within numerous grids and portions of some grids. PC values for each grid were calculated using GIS. The next lower level in the hierarchy is oyster leases, the boundaries of which are digitized and available through LDWF. If any portion of a lease falls within a grid, a PC value of 10% is assigned to that grid. If the grid is not on a lease but within the N-S and E-W boundaries of leased areas, the grid is assigned a value of 3%. The next lower level in the hierarchy is the public grounds off of a mapped reef. Grids within these areas are assigned a PC value of 3%. In the absence of side scan surveys in these areas, the values of PC applied to leases and adjacent bottoms and public grounds off a mapped area is based on professional judgment. Any grid that does not fall in the above areas is assigned a PC value of 0%. It was beyond the scope of the project to digitize existing habitat maps. Because of time constrains, non-digitized sources of information (e.g., Melancon et al. 1998) were not used.

e. Description of Output Data

The model output file provides an HSI value for each 500 x 500m grid for each year. An area with an HSI value ≥ 0.9 is considered optimal for oysters, whereas areas with values of about 0.5 are considered marginal. An HSI value of 0.0 indicates that the habitat is unsuitable (Soniat and Brody, 1988).

f. Statement on the capabilities and limitations of the model

As constructed, the HSI value describes the ability of each spatial unit (500 x 500m grid) to support suitable oyster habitat. Thus, the model does not consider meta-population dynamics whereby, for example, larvae produced from higher salinity environments provide recruits to those in lower salinity ones. In the present model, HSI is calculated in a one-year time step for each spatial unit without the use of historical salinity data. In contrast, the Soniat and Brody

(1988) HSI used long-term historical records to parameterize mean summer water salinity, historic mean water salinity, and frequency of killing floods. The present HSI, however, describes the habitat for a particular year for the given annual salinity regime, without reference to historical salinity trends. Another limitation of the model is the lack of side-scan surveys in a digital format from all oyster grounds, which decreases the certainty of the values applied to percent coverage of the bottom with suitable cultch. Finally, no explicit temperature variable is included. The requirement of a higher salinity during the warmer spawning season is implicitly temperature-dependent. However, although low salinity events (e.g., killing floods, river diversions) during the winter are less detrimental than low salinity during the summer, no explicit temperature dependency is included.

g. Description of model development process including documentation on testing conducted (Alpha and Beta tests)

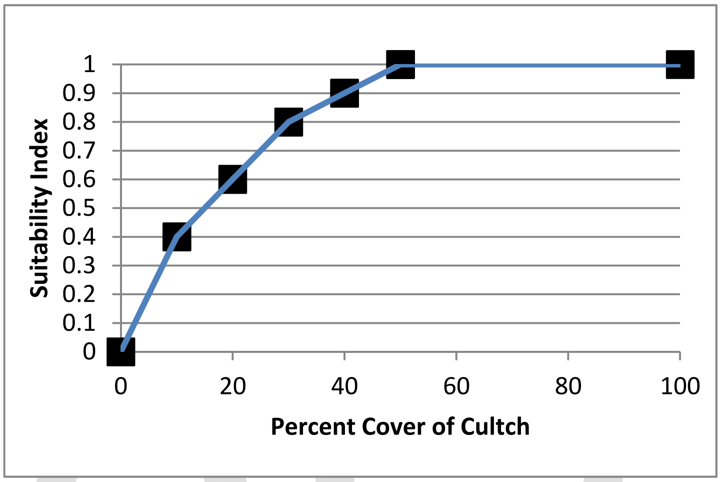
The model developer provided a list of variables, graphical relationships between variables and SI values, and the equation to calculate the HSI from SI values. The model coder wrote the program to calculate HSI values for each 500 x 500m grid and returned a functional test model to the developer. The developer tested the code by inserting example data and determined that the relationships between variable value and SI, and SI and HSI were correct.

2. Technical Quality

a. Theory

Oyster larvae require a hard substrate (cultch) upon which to settle and metamorphose. Suitable substrates are hard bottoms such as natural oyster reefs or shell plants. Shell plants are constructed hard bottoms of natural substrate such as oyster shell or alternative substrate such as limestone. The first step in model development is the determination of variables to be included. The following variables were chosen to represent the minimal requirements of an Oyster HSI. Variable 1 (V_1) is the percent of bottom covered with cultch. A high-quality bottom (grid) is considered to be one in which ≥ 50% is hard substrate (Cake 1983), whereas no hard substrate implies no suitable habitat. Cake (1983) considered the relationship between V_1 and SI_1 to be linear from 0 to 50% cultch. In the present construction, SI values for 10%, 20%, 30% and 40% were explicitly assigned, producing a hyperbolic appearance to the relationship between V_1 and SI_1. The relationship between V_1 and SI_1 is somewhat arbitrary and arguably spatially dependent. At the extremes the relationship is certain – no substrate is unsuitable and 100% coverage is ideal. It is in the intermediate range of PC that the uncertainty arises. Furthermore, the relationship of V_1 to SI_1 *should* be scaled to the explicitly-stated areal unit to which it is applied. For example, requiring 100% PC for an SI of 1.0 in areas of the size of Eco-Hydrology polygons is out of scale, since PC in such large units is never 100% and certainly <10%. Cake (1988) does not explicitly state the areal unit for the determination of percent coverage. Soniat and Brody (1988) field tested the Cake model on 0.1 ha sites. In the present model, the areal unit is a 500 x 500m grid. At such, a relatively small scale requiring 100% PC for an SI of 1.0 is within a reasonable spatial scale; in fact, some of the grids did achieve this standard. Since no complete data set exists from which PC values could be generated, an approach based upon a hierarchy of data quality and surrogates of percent coverage was used (see 1.d. above). Unlike the salinity values that change with each model run (i.e., each year), grid percent coverage with cultch is typically the same for all model runs (and years). Changes in the static cultch file are, however, allowed in three special conditions. (1) Reef projects that add cultch to the bottom. Grids can be modified to reflect the new conditions. Grids are assigned PC values according to project specifications or outcomes. This exception allows for the inclusion of restoration projects such as reef building to enhance oyster habitat. (2) Manipulations of the cultch grid to allow for identification of potential for oyster habitat if salinity is suitable. Artificially setting a PC value in selected grids (in addition to the static PC file) and calculating the HSI value provides a tool for locating areas for reef projects such as those described in (1) above. (Potential oyster habitat can also be identified by a four variable model which excludes PC, as discussed below.) (3) Allowances for land loss (newly created open water areas) to become suitable oyster habitat, by implementing model code changes that incorporate percent land. The default PC for newly created open water is 0%, but can be adjusted for scenarios incorporating proposed reef construction (as in 1 above) or for selecting locations for reef construction (as in 2 above).

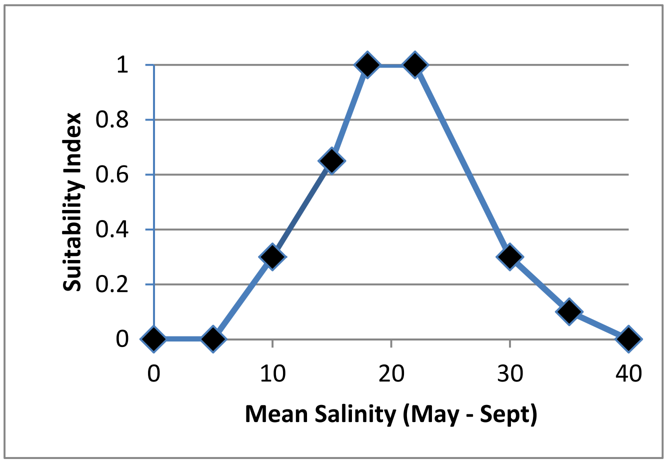
$SI_1 =$ 0.0 for V1 = 0
0.4 for V1 = 10
0.6 for V1 = 20
0.8 for V1 = 30
0.9 for V1 = 40
1.0 for V1 = 50
1.0 for V1 = 100



Three salinity-based variables, which describe different aspects of the oyster's dependency on salinity, are defined. Oysters require a higher salinity for spawning than for survival of adults. An annual mean salinity designates an expected range over which oysters exist and an optimum range over which they thrive, and a minimum salinity describes the potential impacts of killing floods. Salinity values are derived from the spatially-referenced data in polygons provided by the Eco-Hydrology model. See 1.d. above for the method by which monthly salinity values were interpolated for this model. These interpolated monthly values for each 500 x 500m grid were used to derive values for each of the following salinity-based variables.

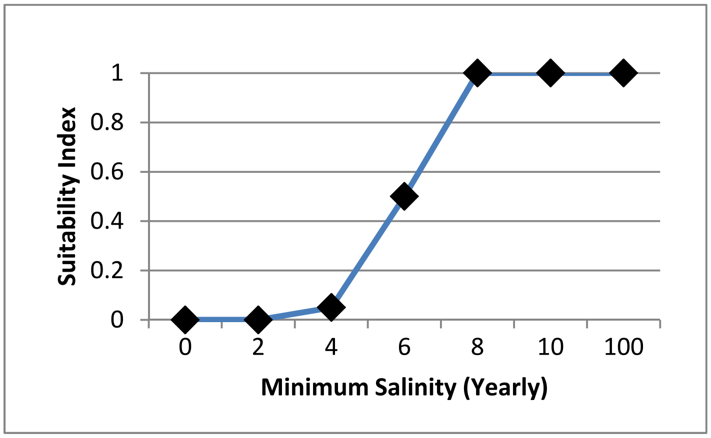
Variable 2 (V_2) is the mean salinity during the spawning season. The value applied is the mean of the monthly May through September salinities for each 500 x 500m grid. This variable reflects the higher optimal salinities required for spawning as opposed to the optimum salinity requirements of adults (Butler 1954, Cake 1983).

SI_2 = 0 for V2 = 0
0 for V2 = 5
0.3 for V2 = 10
0.65 for V2 = 15
1.0 for V2 = 18
1.0 for V2 = 22
0.3 for V2 = 30
0.1 for V2 = 35
0 for V2 = 40



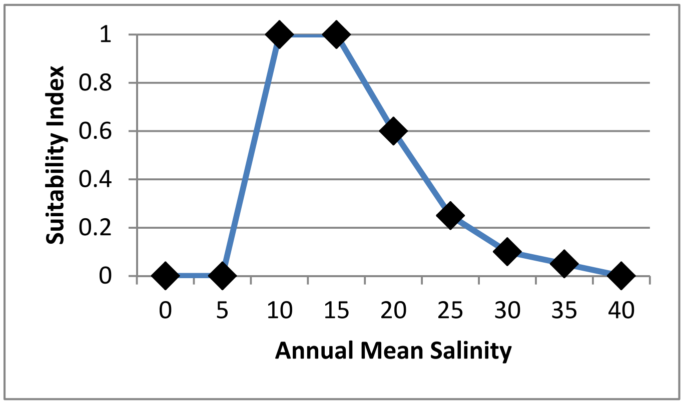
Variable 3 (V_3) is the minimum salinity, i.e. the minimum value of the 12 monthly mean salinities for each 500 x 500m grid. Minimum salinity values were derived from the spatially-referenced data in polygons provided by the Eco-Hydrology model after linear interpolations were made across salinity gradients, and each grid was populated with a monthly salinity value. The lowest value of monthly salinity was used as the minimum salinity. Minimum salinity is a surrogate for frequency of killing floods in the models of Cake (1983) and Soniat and Brody (1988), which require long-term historical salinity data sets for parameterization. This variable is essential to describe impacts of freshwater diversions or hydrological alterations. Low salinity has a greater negative impact in the summer than in the winter; however, the model does not include a temperature effect. Furthermore, the relationship between minimum salinity and SI does not describe any potential positive benefits of killing floods, such as reducing predators and disease (Butler 1953, Gunter 1979, Mackin 1962, LaPeyre et al. 2009).

SI_3 = 0.0 for V3 = 0
0.0 for V3 = 2
0.05 for V3 = 4
0.5 for V3 = 6
1.0 for V3 = 8
1.0 for V3 = 10



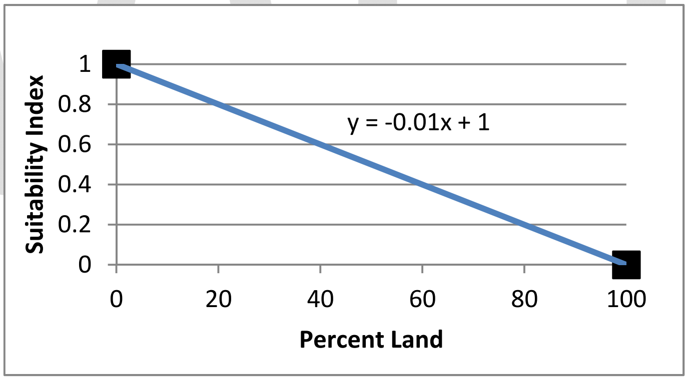
Variable 4 (V_4) is annual mean salinity. The value for V_4 is the grand mean of the 12 monthly mean salinities for each 500 x 500m grid. Annual mean salinity defines the range over which adult oysters survive and thrive (Gunter 1955, Calabrese and Davis 1970, Castagna and Chanley 1973, Cake 1983, Chatry et al. 1983). The relationship between V_4 and SI_4 follows that of Soniat and Brody (1988), with the exception that the optimum annual mean salinity in the present HSI is a range (10 to 15 ppt) and not a discrete point (12.5 ppt).

SI_4 = 0.0 for V4 = 0
0.0 for V4 = 5
1.0 for V4 = 10
1.0 for V4 = 15
0.6 for V4 = 20
0.25 for V4 = 25
0.1 for V4 = 30
0.05 for V4 = 35
0.0 for V4 = 40



Variable 5 (V_5) is percent land. It restricts oysters to aquatic habitats by excluding terrestrial habitats. This variable is used to scale all of the others since they are based on a full 500 X 500m grid cell, but water may not cover the entire cell. NOTE: Use Percent Land as a percentage in the equation, but V_5 is reported as a value between 0 and 1. This is an output from the Wetland Morphology model (see Appendix D-2).

$V_5 = (-0.01 * \%Land) + 1$
$SI_5 = V_5$



An annual HSI value is calculated for each 500 x 500m grid. HSI is determined as the un-weighted geometric mean of the Suitability Index (SI) values for the five component variables, where:

$$HSI = (SI_1 * SI_2 * SI_3 * SI_4 * SI_5)^{1/5}$$

b. Description of system being represented by the model

The Oyster HSI is applicable to the brackish waters and associated water bottoms of coastal Louisiana. The components of the model, as represented by the model variables, are percent coverage of the bottom with suitable cultch, mean salinity during the spawning season, minimum annual salinity, annual mean salinity, and percent land. The first component, percent coverage, requires that the bottom be covered with suitable cultch to attract settling larvae and support adult oysters. The second component, mean salinity during the spawning season, recognizes the requirement of higher salinities for spawning of adults, survival of larvae, and successful spat set than for adult maintenance and survival. The third component, minimal annual salinity, models the detrimental effects of low salinity events (e.g., killing floods). The fourth component, annual mean salinity, represents the maintenance and survival requirements of post-settlement stages. The final component, percent land, allows for modification of HSI as land is eroded or restored.

c. Analytical requirements

The model requires spatially referenced monthly mean salinities, percent coverage of the bottom with suitable cultch and percent land. As mentioned above, greater spatial resolution of salinity was required than that available. To further resolve salinities, the Eco-Hydrology polygon map was overlaid by a 500 x 500m grid, linear interpolations were made across salinity gradients, and each grid was populated with a monthly salinity value. These interpolated monthly values for each 500 x 500m grid were used to derive values for the salinity-based variables – mean annual salinity, minimum monthly salinity and mean salinity during the spawning season. Percent coverage of bottom with cultch in 500 x 500m grids was generated by procedures described above. Percent land values for each 500 x 500 m grid were generated from a percent land map provided by the Wetland Morphology model.

d. Assumptions

The overarching assumption of the Oyster HSI is that oyster habitat quality can be described as suitable salinity over suitable substrate (cultch). Oysters are a well-studied species for which we generally have an abundance of information to relate variable value to suitability index (SI). The salinity variables are probably well-constrained, the percent coverage of cultch less so. Setting 50% cultch coverage to a SI of 1.0 seems somewhat arbitrary. In the original Cake (1983) model, a PC of greater than or equal to 50% was considered optimal (SI = 1.0), and 0% coverage was unsuitable (SI = 0). For the Cake model, the relationship was linear between 0 and 50%. As discussed above, all we really know is that 0% is "unsuitable" and 100% is "optimal". In the present HSI, the relationship between PC and SI is more hyperbolic, resulting in higher SI values between 0 and 50% coverage. The relationship could just as well be defined as a linear relationship or a hyperbolic curve with 0% = 0 and 100% = 1.0. Another issue is the quality of the data to convert variable value to SI. The poorest data by far are the cutch data. In the absence of hard data, surrogates were used.

The salinity variables used in the model were chosen with an understanding of the nature of the data which were available. There was no historical salinity data upon which to draw, only monthly mean salinity for each year for each Eco-Hydrology polygon. Variable 2 is the mean salinity during the spawning season which was constructed as the mean salinity of May through September means. Variable 3 was designed as an annual surrogate for an historical variable of Cake (1983), namely the frequency of killing floods. Likewise, variable 4 is an annual representation of Cake's historical mean salinity. The present model is thus an evaluation of habitat quality for a year only, without any implication of its historical value. The salinities are provided by the Eco-Hydrology model. As previously described, monthly salinity values were interpolated for each 500 x 500m grid. Nonetheless, the salinity data and relationship of variable to SI are fairly well constrained. The greatest uncertainty in the model likely arises from inadequate information on bottom type. This modeling exercise clearly identifies the need for better information on bottom type in a digital format.

All variables are given equal weight in the calculation of the HSI. Variable values that fall between nodes are assigned SI values calculated by linear interpolation between the two closest defined nodes.

e. Identification of formulas used in the model and proof that the computations are appropriate and done correctly

The model developer was provided a utility to calculate SI and HSI from input of variable values. He validated that the calculations of SI and HSI were correct. The model decision rules that were coded are provided in section 2.a. above, and the model code will be provided to CPRA.

3. System Quality

a. Description and rationale for selection of supporting software tool/programming language and hardware platform

Building upon the ecological modeling application development performed for the Everglades modeling community, Java was used as the programming language inside the Eclipse RCP environment which supports plug-in software development. This approach facilitated the construction of software suites which execute the specific decision rules provided by subject matter experts allowing an end-user to choose which of the ecosystem services models to run.

b. Proof that the programming was done correctly

All software products are the result of multiple programmers working in concert. As part of the code development process, code classes are either team developed which ensures multiple individuals real-time code review or when individually coded are spot checked prior to production builds and exports.

c. Availability of software and hardware required by model

The choice of Java as the development platform ensures the broadest execution platform. These software suites can run on desktops with the following operating systems: Windows XP, 7 (32 and 64 bit), Apple OSX (32 and 64 bit), Linux. Furthermore, these Java executables could be easily re-compiled to run on Windows or Linux Application Servers.

d. Description of process used to test and validate model

As mentioned above, a utility provided to the model developer was used to test the calculations of SI and HSI from test input of variables. The model developer also reviewed a visualization of HSI calculations from across the coast. Grids were colorized according to HSI value, which allowed visualization of HSI model results on a grand scale.

e. Discussion of the ability to import data into other software analysis tools (interoperability issue)

Being standards compliant with international modeling data standards ensures rather broad interoperability. Unidata actively supports netCDF read/write libraries for C++, Java, C# and Fortran programming languages across multiple operating systems. Additionally, netCDF is natively consumable by commercial software product such as ESRI ArcMAP and MatLab.

Furthermore, the Everglades Joint Ecologic Modeling community has backed a USGS software development effort resulting in EverVIEW which brings an open-source visualization platform solution to the complex realm of binary modeling data.

4. Usability

a. Availability of input data necessary to support the model

The input files required to run this model are available through the CPRA.

b. Formatting of output in an understandable manner

The output data is a suitability index ranging from 0.0 to 1.0 that represents the potential for agriculture/aquaculture of a 500 x 500m model grid cell. The output files are in netCDF format and can be viewed using EverVIEW or ArcGIS.

c. Usefulness of results to support project analysis

The model is useful in determining the effects of coastal protection and restoration projects on oyster habitat. Any restoration project that modifies salinity, plants or buries cultch, or creates or eliminates land modifies the Oyster HSI.

d. Ability to export results into project reports

The model output is in netCDF format, which provides both a graphical and tabular representation of the model results that can be incorporated into reports. Model outputs can also be imported into ESRI ArcMap.

e. Training availability

Training for model usage would be provided through CPRA.

f. Users documentation availability and whether it is user friendly and complete

There are currently no user's guides or technical manuals to support the model; however, the model does have a help screen that explains how to convert model inputs into the necessary format as well as which files are necessary to run the model.

g. Technical support availability

Access to technical support would be provided through CPRA.

h. Software/hardware platform availability to all or most users

The ecosystem services modeling suite, being coded in Java, will run on most operating systems.

i. Accessibility of the model

Access to model and associated installation and execution files would be provided through CPRA.

j. Transparency of model and how it allows for easy verification of calculations and outputs

HSI values must be between 0 and 1, and if salinity inputs reflect historic values the HSI should track oyster distribution. Model code will be provided to CPRA.

5. *Sources of model uncertainty*

The habitat and salinity requirements of oysters are well known (Cake 1983, Soniat and Brody 1988, Barnes et al. 2007). The likely greatest source of uncertainty in the model is from the uncertainty in the data used to support it. By far the greatest uncertainty arises from inadequate information on bottom type. A 500 x 500m grid overlay of the coast was created and populated with PC data of greatly varying quality. The salinity data used as input to the model were provided by the Eco-Hydrology model and are subject to any errors inherent in the modeling process. Spatially-referenced salinity data was provided in polygons of various shapes and sizes. Unfortunately, the polygons were too large for resolution of an Oyster HSI; furthermore, the polygons were almost always oriented perpendicular and not parallel to the salinity gradient. The 500 x 500m grid overlay was also used to provide greater spatial resolution of salinity. Each grid was populated with a salinity value by linear interpolation of salinity from the polygons. This procedure, although necessary, introduces an additional uncertainty.

6. *Suggested model improvements*

The 500 x 500m grid overlay provides a framework for all future improvements to the PC map. The upgrading of the PC map should be an ongoing effort as analog data becomes digitized, new surveys are conducted, and new restoration projects are completed. Greater spatial resolution of salinity than that provided by the hydrology polygons is required. It would be helpful if the spatial resolution of the salinity data was 500 x 500m. The model could be modified to include a temperature effect on minimum salinity. For example, low salinity in the cold months is less detrimental than low salinity in the warm months. The model could thus include two different relationships between V_3 and SI_3 – one for the cold months and one for the warm months. Such a change would likely have little effect on outcomes, since minimum salinity is well constrained in the present model. The model does not use nor require historical data. However, if such data were compiled, model simulations could be run and the results compared to actual oyster distributions. Previous models (Cake 1983, Soniat and Brody 1988) have included predators and disease. The inclusion of these biological variables is outside of the scope and nature of the present model. It is assumed that the impacts of disease and predators, which are more prevalent at higher salinities, are subsumed by V_4, annual mean salinity. The relationship between PC (V_1) and SI_1 could be simplified as a linear one with V_1 at 0 % cultch delegated a SI_1 of 0, and a V_1 at 100% cultch delegated a SI_1 of 1.0. The relationship between V_1 and SI_1 will be subjected to an uncertainty analysis (see below).

7. *Quality review*

Specific QR procedures for the Oyster HSI to support the 2012 Coastal Master Plan included comparison of modeled predictions with expected outcomes given the known inputs. The modeling team used known spatial and temporal patterns in input to quality check patterns in habitat quality for the species.

8. *Uncertainty analysis*

The Oyster HSI has a total of four variables and decision rules that determine the overall HIS in each grid cell. According to discussions with the model team, the percent cultch variable and its decision rule was included in the uncertainty analysis. See Appendix D-27 Model Uncertainty Analysis for more detailed information.

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