ERDC/EL SR-22-4

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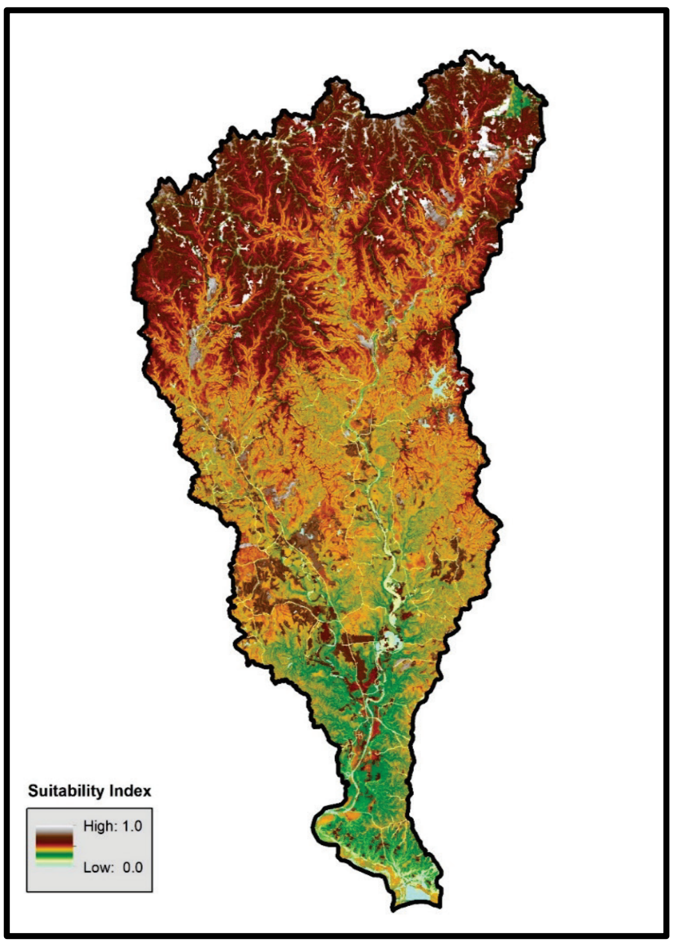
Ecosystem Management and Restoration Research Program

Geospatial Suitability Indices (GSI) Toolbox

User's Guide

Christina Saltus, S. Kyle McKay, and Todd Swannack

August 2022



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Ecosystem Management and Restoration
Research Program

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US Army Engineer Research and Development Center
Environmental Laboratory
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final Special Report (SR)

Approved for public release; distribution is unlimited.

Prepared for Ecosystem Management and Restoration Program
Environmental Laboratory
US Army Engineer Research and Development Center
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Under Project Number 476549, Improving USACE Ecological Modeling

Abstract

Habitat suitability models have been widely adopted in ecosystem management and restoration to assess environmental impacts and benefits according to the quantity and quality of a given habitat. Many spatially distributed ecological processes require application of suitability models within a geographic information system (GIS). This technical report presents a geospatial toolbox for assessing habitat suitability. The geospatial suitability indices (GSI) toolbox was developed in ArcGIS Pro 2.7 using the Python 3.7 programming language and is available for use on the local desktop in the Windows 10 environment. Two main tools comprise the GSI toolbox. First, the suitability index (SIC) calculator tool uses thematic or continuous geospatial raster layers to calculate parameter suitability indices using user-specified habitat relationships. Second, the overall suitability index calculator (OSIC) combines multiple parameter suitability indices into one overarching index using one or more options, including arithmetic mean, weighted arithmetic mean, geometric mean, and minimum limiting factor. The result is a raster layer representing habitat suitability values from 0.0–1.0, where zero (0) is unsuitable habitat and one (1) is ideal suitability. This report documents the model purpose and development and provides a user's guide for the GSI toolbox.

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Preface

This study was conducted by the US Army Engineer Research and Development Center (ERDC)'s Environmental Laboratory (EL) for the Ecosystem Management and Restoration Research Program (EMRRP), under Project 476549, "Improving USACE Ecological Modeling." The EMRRP is sponsored by Headquarters, US Army Corps of Engineers (USACE), and is assigned to ERDC under the purview of EL in Vicksburg, Mississippi. The EMRRP program manager was Dr. Brooke Herman.

This work was performed by the Environmental Systems Branch, Wetlands and Coastal Ecology Branch, and Ecological Resources Branch of ERDC-EL. Technical peer reviews were conducted by Mr. Sam Jackson and Dr. Glenn Suir of the ERDC-EL.

At the time of publication, Mr. Mark R. Graves was the chief of the Environmental Systems Branch; Mr. Mark D. Farr was chief of Ecosystem Evaluation and Engineering Division; Dr. Christine VanZomeren was the associate technical director for Civil Works Environmental Engineering and Sciences; Dr. Jennifer Seiter-Moser was the technical director for Civil Works Environmental Engineering and Sciences; and the ERDC-EL director was Dr. Edmond J. Russo Jr.

The commander of ERDC was COL Christian Patterson and the director was Dr. David W. Pittman.

1 Introduction

1.1 Background

Ecological models such as habitat suitability often provide a means to forecast and estimate outcomes of management decisions in the US Army Corps of Engineers (USACE). For instance, the potential impact to wetland systems from an infrastructure project such as a levee might require associated mitigation actions or costs. Conversely, a proposed restoration action could provide ecological benefits to an imperiled species. Habitat suitability models are common ecological modeling methods that index the quality of an ecosystem relative to a particular taxa or ecological outcome (Swannack, Fischenich, and Tazik 2012). Habitat quality (that is, suitability) is then combined with habitat quantity as an overall metric of ecological impact or benefit.

Habitat suitability models, such as those developed by US Fish and Wildlife Services (USFWS) in the 1970s–1980s, have played a key role in supporting environmental management decisions nationwide (USFWS 1980a, 1980b; USFWS 1981). The USFWS models describing the quantitative relationships between species and habitat were generally based on a combination of literature, field studies, and expert opinion, and the reports are colloquially referred to as the *blue books* because of the blue covers binding the original publications. Although the species-centric approach remains central to index modeling, these models have also been used at the community- and ecosystem-level (for example, the hydrogeomorphic method of wetland assessment, https://wetlands.el.erdc.dren.mil/guidebooks.cfm).

Index models of habitat generally relate multiple independent variables (for example, forest cover, edge density) to a relative assessment of suitability on a 0.0–1.0 scale. The overall habitat suitability index (HSI) is then assessed as a combination of multiple suitability indices through a specified statistical method (for example, arithmetic mean, geometric mean, minimum).

1.2 Objective

Index-based habitat suitability models are frequently used to help inform decision-making for ecosystem restoration planning. Current USACE practice often requires that these models be developed rapidly to meet accelerated planning deadlines. While a variety of tools for rapidly developing spatially implicit models exist (see, for example, the Toolkit for interactive Modeling, or TAM, developed by Carrillo, McKay, and Swannack 2020 or the ecorest, developed by McKay and Hernández-Abrams 2020), similar rapid-assessment methodologies for spatial data lack options. Therefore, this report addresses the need for a set of computational tools to assess ecological outcomes with index models within a GIS.

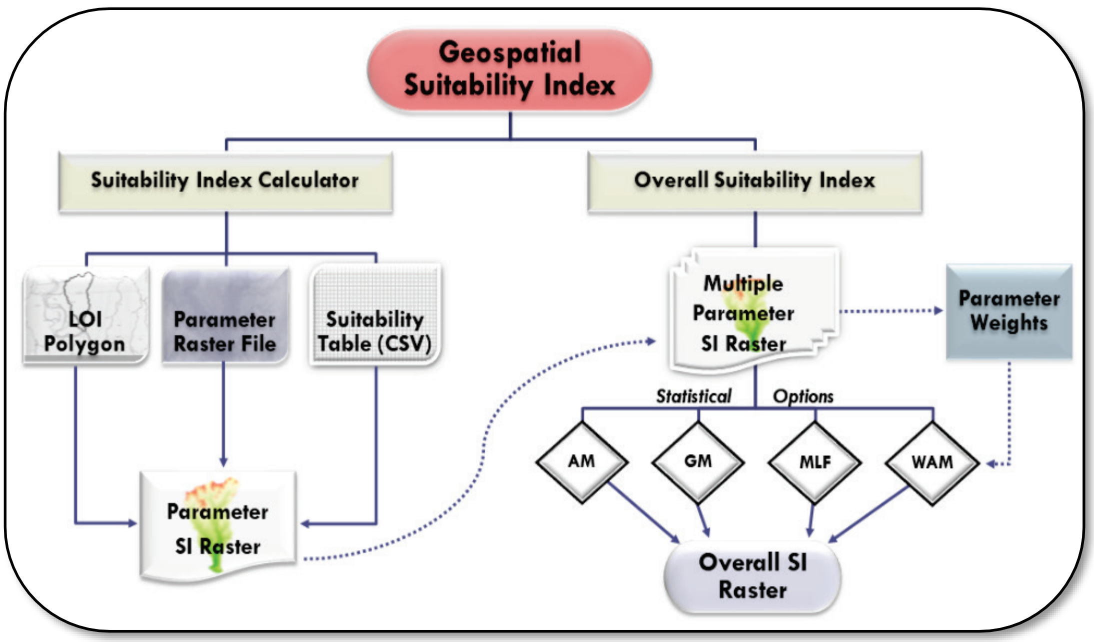
1.3 Approach

This user's guide provides documentation of the geospatial suitability indices (GSI) toolbox usage as well as relevant information for USACE model certification (EC 1105-2-412, USACE 2011; PB 2013-02, USACE 2013). The GSI toolbox uses thematic- and continuous-raster data sets to create and integrate multiple ecosystem parameter indices (that is, habitat suitability indices) into a single raster layer representing environmental habitat suitability for a system of interest. The toolbox provides a streamlined approach to working with regional geospatial data sets in an easy-to-use, index-based modeling framework that can incorporate regional value ranges from multiple parameters. Two tools are available in the GSI toolbox (Figure 1):

1. A suitability index calculator (SIC) that uses thematic or continuous geospatial raster layers to calculate individual suitability indices using the relationship between the habitat and suitability of the physical environment.
2. An overall suitability index calculator (OSIC) that combines parameter suitability indices into one overall suitability index representing the spectrum of the entire spatial domain. OSIC uses one or more of the following statistical options: arithmetic mean, weighted arithmetic mean, geometric mean, and minimum limiting factor. The output is a raster layer representing suitability values from 0.0 to 1.0, where zero (0) is nonsuitable habitat and one (1) is the most suitable.

The SIC and OSIC can be used as stand-alone tools. The SIC's primary purpose is to develop multiple raster layers of different components of the species-environment relationship, and the OSIC's primary purpose to combine those layers into a single layer representing overall habitat suitability as defined by integrating the SIC layers.

Figure 1. Geospatial suitability indices (GSI) toolbox workflow diagram. (AM—arithmetic mean; GM—geometric mean; MLF—minimum limiting factor; and WAM—weighted arithmetic mean) (Note: accessible version of figure available in Appendix)



2 Model Development Process

The GSI toolbox development process follows the guidance provided by Grant and Swannack (2008) for common suitability-index-based modeling approaches. The model concept was developed through discussions with the project development team to determine a model workflow and implementation plan. Generalized index-model calculation methods were identified and quantified. Then, the model was evaluated according to technical quality, system quality, and usability to meet the required standards outlined in the USACE certification guidelines (USACE 2011). Finally, communication and application of the model was provided via a user's guide and an example USACE restoration-project application. GSI toolbox was tested by a US Army Engineer Research and Development Center (ERDC) Environmental Laboratory scientist and is available for download with the user's guide from ERDC Knowledge Core (https://erdc-library.erdc.dren.mil/).

2.1 Conceptualization

Index-based habitat suitability models are frequently used to inform ecosystem decision-making such as restoration planning, habitat evaluation procedures, and invasive species management (Curnutt et al. 2000; Swannack, Reif, and Soniat 2014; Shafer et al. 2016). The conceptualized model was designed to couple rapid approaches for index-based ecological modeling with geospatial analytics. The following topics guided model conceptualization and development:

- model purpose—Ad hoc execution of index models based on geographic information system (GIS) analyses is leading to significant USACE investments in computational tool development, user learning, model review, and certification. This platform intends to provide an error-checked, computationally accurate tool for suitability outcomes for raster data sets.
- target application—This toolkit is intended primarily for USACE ecosystem restoration planning; however, index models are also often applied for impact assessment, compensatory mitigation, and wetland regulatory issues.

- target users—The primary audience for these tools are USACE planners, biologists, and engineers involved in ecosystem-restoration projects who already have familiarity with GIS analyses.
- flexible design—The toolbox is agnostic to the data type or index model type.
- bound the system of interest—A multicriteria index model of an ecosystem defining the quality of suitable habitat. Habitat suitability is defined as an index score from 0.0 to 1.0, where zero (0) is less suitable habitat and one (1) is the most suitable. The assignment of scores is based on individual parameter values and suitability index tables developed from peer-reviewed literature, expert opinion, or existing USACE-certified models.
- model objective—Ultimately, the overarching objective of this tool is to develop a technically sound and computationally accurate suite of GIS tools for index modeling of raster data.

2.2 Quantification

2.2.1 Modeling approach

The model incorporates raster-based geospatial layers and habitat-suitability relationship tables to generate suitability indices defining the species-habitat relationship. While the model supports the creation of one parameter suitability index at a time, an unlimited number of indices can be generated. However, the overall habitat suitability index can only accept a maximum of ten parameter suitability indices. This limit ensures optimal performance of the toolbox and decreased computational time while providing sufficient input necessary for generating overall habitat suitability.

2.2.1.1 Key assumptions

1. User-defined suitability tables used as input into the tool may be developed from peer-reviewed literature, expert opinion, or existing USACE-certified models and follow the formatting requirements provided in the user's guide and help documentation.
2. Input-parameter raster data are provided in the appropriate spatial scale to capture the ecosystem environment.
3. The temporal scale for each input data source adequately defines the parameter's relationship to the species or habitat and association to other parameters.

4. Input suitability-index tables include a minimum of two data points and associated suitability-index values to adequately define the species-habitat relationship.
5. Input parameter values use the same measurement units as the suitability-index tables.

2.2.1.2 Key limitations

1. Input parameter data are only acceptable in a raster-data format containing spatial-reference information and in a format compatible with ArcGIS. Vector-based GIS data are not accepted as parameter input.
2. For iterative SIC tool runs intended as input into the OSIC tool, all raster data should have the same spatial resolution (that is, cell size), spatial extent, and spatial reference.
3. While the GSI toolbox can be applied to areas worldwide where applicable data are available, it is best suited for local and regional areas depending on input file size, computer memory, and file storage capacity.

2.2.2 Functional form

A stepwise implementation of the linear-regression formula for continuous-input parameter data calculates parameter suitability index raster values using the suitability-index tables defining the relationship between the parameter values and its suitability-index score. First, the model sorts the rows in the suitability-index table (comma separated value, CSV; Equation 6) in ascending order using the user-selected parameter data field. Then, the data values and associated suitability values from the first two rows of the table (excluding header row) are used to calculate the slope of the line (Equation 1), y-intercept (Equation 2), and linear-regression formula (Equation 3). Next, the linear-regression formula is applied to each pixel within the parameter raster that meets the data-value range threshold as defined in the first two rows of the suitability index table and generates the output parameter suitability index raster. If more than two rows are present in the CSV table, the model will advance one row down and apply the formulae to the second and third rows, then third and fourth rows, and so on until no data values remain.

The slope of the line (β_1) is calculated using the formula shown in Equation (1), where x_1 is the first data-point value, x_2 is the second data-point value, y_1 is the first suitability-index score, and y_2 is the second suitability-index score from the suitability-index table, respectively.

$$\beta_1 = \frac{y_2 - y_1}{x_2 - x_1} \tag{1}$$

The y-intercept (β_0) is calculated using the formula shown in Equation (1), where $\bar{y}$ is the mean of y_1 and y_2, $\bar{x}$ is the mean of x_1 and x_2 from Equation (1), and β_1 is the slope of the line.

$$\beta_0 = \bar{y} - \beta_1 \bar{x} \tag{2}$$

The linear regression formula is defined in Equation (3), where Y is the suitability score value, X is the input parameter value, β_1 is the slope of the line between two CSV data points (Figure 3), and β_0 is the y-intercept.

$$Y = \beta_0 + \beta_1 X \tag{3}$$

The following formulas are statistical options available in the model for calculating overall habitat suitability indices from multiple parameter suitability indices. These options include arithmetic mean (AM), weighted arithmetic mean (WAM), geometric mean (GM), and minimum limiting factor (MLF).

2.2.2.1 Arithmetic mean (AM)

The AM calculates the average value of all overlapping parameter pixels, on a pixel-by-pixel basis, where all values are assigned equal importance. The values are summed and then divided by the total number of raster values provided in Equation (4), where PSI_i is equal to the parameter suitability index pixel value for each parameter i, and n represents the total number of input parameters.

$$\mathrm{AM} = \frac{1}{n}\sum_{i=1}^{n} \mathrm{PSI}_i \tag{4}$$

2.2.2.2 Weighted arithmetic mean (WAM)

The WAM calculates the average value of all overlapping parameter pixels, on a pixel-by-pixel basis, where all values are assigned a specific integer weight (ranging from 1 to 100), as shown in Equation (5), where PSI_i is equal to the parameter suitability index pixel value for each parameter i,

PSI_w is the weight of each parameter, and n represents the total number of input parameters.

$$\text{WAM} = \sum_{i=1}^{n} \frac{\text{PSW}_w}{100} \times \text{PSW}_i \tag{5}$$

2.2.2.3 Geometric mean (GM)

The GM is calculated on a pixel-by-pixel basis for the overlapping pixel values of all selected parameter rasters, as shown in Equation (6), where, PSI_i is equal to the parameter suitability index pixel value for each parameter i, and n represents the total number of input parameters.

$$\text{GM} = \left(\prod_{i=1}^{n} \text{PSI}_i\right)^{\frac{1}{n}} \tag{6}$$

2.2.2.4 Minimum limiting factor (MLF)

The MLF method identifies the minimum value of each pixel according to a multiple parameter suitability index raster-layer overlay operation in ArcGIS (Esri 2019). This method uses the Local Cell Statistics function in Spatial Analyst Tools.

2.3 Evaluation

The GSI toolbox was evaluated according to technical quality, system quality, and usability to ensure that tool components meet the required standards outlined in the USACE certification guidelines (USACE 2011; USACE 2013).

2.3.1 Technical quality

This model relies on habitat suitability index curves developed from peer-reviewed literature, expert opinion, and existing USACE-certified models (specifically those provided with this model and described in USFWS 1980b and McKay and Hernández-Abrams 2020). The calculation of output parameter habitat suitability indices is based on these curve values supplied as a CSV table, where each row of the table contains a variable value within one field representing the x-axis and the corresponding suitability score within the second field denoting the y-axis. For continuous-raster input, a linear-regression formula is applied in a stepwise approach between each data point to convert parameter raster pixel values to HSI values. For thematic-raster input, raster data categories are matched to the variable value in the CSV table, and then suitability scores are assigned to each pixel value in the output raster. Statistical calculations commonly used for generating overall habitat suitability (that is, AM, WAM, GM, and MLF statistics) were implemented using Raster Math functions in ArcGIS software (Shafer et al. 2016; Draugelis-Dale 2007; Store and Kangas 2001). The model was developed to address habitat quality and quantity.

2.3.2 System quality

ArcGIS Pro and ArcGIS software (Esri, Redlands, California) were used as part of the test strategy to validate the accuracy of the model calculations and output values. First, a random sampling method was used to create an Esri point feature class of 100 randomly sampled points throughout an input parameter raster. Then, the Extract Multi Values to Points command was implemented to store parameter values associated with each point location in the feature class. Finally, manual application of the HSI formula and statistical calculation formulas were used to compare each sample point value to the model’s output values. To test unexpected value ranges for input parameters, a test raster was generated in ArcGIS using the Create Random Raster tool with a uniform distribution containing minimum and maximum values beyond expected values.

Quality assurance measures were taken within the Python coding to document the model’s workflow and capture errors as well as provide error messages to the user.

2.3.3 Usability

Spatial processes are major drivers in all ecosystem dynamics, for example, invasive species colonization. Also, spatially explicit data and methodologies have proven to be successful in studies related to invasive species detection and habitat suitability (Shafer et al. 2016; Swannack, Reif, and Soniat 2014). Therefore, the development of the GSI toolbox in spatially enabled software was needed to capture those drivers. Besides being technically sound, ArcGIS software was chosen for model development because it is a commonly used geospatial software application by USACE and is approved by the information technology and information management division (ACE-IT) of USACE. Python coding software was selected for toolbox development since it is flexible and provides enhanced capabilities with no additional installation requirements.

Numerous raster file formats consistent with ArcGIS standards, such as geotiff, ESRI GRID, and ERDAS Imagine, are accepted as data inputs and outputs for this model. In addition, the output raster data contain spatial reference information for use by other GIS-based software applications.

3 Geospatial Suitability Indices (GSI) Toolbox User's Guide

The GSI toolbox is an ArcGIS Pro–based HSI toolbox developed using the Python programming language. The toolbox creates parameter suitability indices such (that is, elevation and slope) using the species-habitat relationship and combines ecosystem parameter indices into a single raster layer representing relative environmental habitat suitability. The user's guide provides a detailed description of data inputs and outputs for each tool in the model, including the required and accepted file formats, tool workflows, and troubleshooting guidance and best practices. In addition, help documentation is included within the model for each required data input. Additional technical support is available by contacting the model developer.

3.1 System requirements

The GSI toolbox can be used with ArcGIS Pro 2.7–2.9 software but was specifically tested on versions 2.7 through 2.7.2 and is based on the Python programming language (version 3.7). The toolbox requires a Windows 10 operating system environment, an Advanced ArcGIS Pro license with Spatial Analyst Extension, and Python version 3.7. Python is automatically installed and available for use with ArcGIS during the default installation.

3.2 File structure

The files comprising the GSI toolbox are provided in a zip file, `GSI_Toolbox.zip`, which can be downloaded from ERDC Knowledge Core (https://erdc-library.erdc.dren.mil/). Table 1 provides a list of file names and descriptions of each file included in the toolbox.

Table 1. Files included with the GSI toolbox.

File name	Description
`GSI_Toolbox.pyt`	Principal ArcGIS Python toolbox file for the Geospatial Suitability Indices (GSI) toolbox, which manages and directs all related Python code
`GSI_Toolbox.pyt.xml`	Help documentation for the GSI toolbox
`GSI_Toolbox.WeightedSITen.pyt.xml`	Help documentation for the GSI toolbox, Overall Suitability Index Calculator (OSIC) tool

File name	Description
`GSI_Toolbox.SICombined.pyt.xml`	Help documentation for the GSI toolbox, Suitability Index Calculator (SIC) tool
`Scripts` folder	
`ClipRaster2AOI2.py`	Python code, as part of the SIC tool, for clipping an input parameter raster by the location of interest (LOI) polygon
`CombinedTools.py`	Python code for the SIC tool
`GSI_calculator.py`	Python code, as part of the SIC tool, for conversion of input parameters to suitability indices
`WeightSITool.py`	Python code for the OSIC tool
`SuitabilityTables` folder	
Suitability-index tables	Comma-separated value (CSV) formatted tables, which describe the species-habitat relationship for several defined parameters. The files are arranged by species name and are located in the `SuitabilityTable` folder provided with the tool download
`SampleData` folder	
`NLCD2016_NAD83.img` (Thematic raster)	National Landcover Data set (NLCD) 2016, 30 m* (Jin et. al. 2019)
`LANDFIRE2016_DEM.tif` (Continuous raster)	LANDFIRE 2016 Digital Elevation Model (DEM), 30 m, (LANDFIRE 2016)
`LANDFIRE2016_Slope.tif` (Continuous raster)	LANDFIRE 2010 Percent Slope, 30 m (LANDFIRE 2016)
`BayouSara_HUC10.shp` (LOI polygon)	Esri polygon shapefile representing an LOI (hydrologic unit code [HUC] 10 boundary for Bayou Sara, Louisiana / Mississippi)

3.3 Toolbox installation

To install the GSI toolbox, download the toolbox and extract the zip file, `GSI_Toolbox.zip`, to a local folder on your computer. In the ArcGIS Pro catalog window, right-click on the Toolboxes folder and select Add Toolbox (Figure 2). Navigate to the local folder, select the toolbox file (`GSI_Toolbox.pyt`), and click OK. Make sure the Spatial Analyst Extension is activated prior to using the toolbox.

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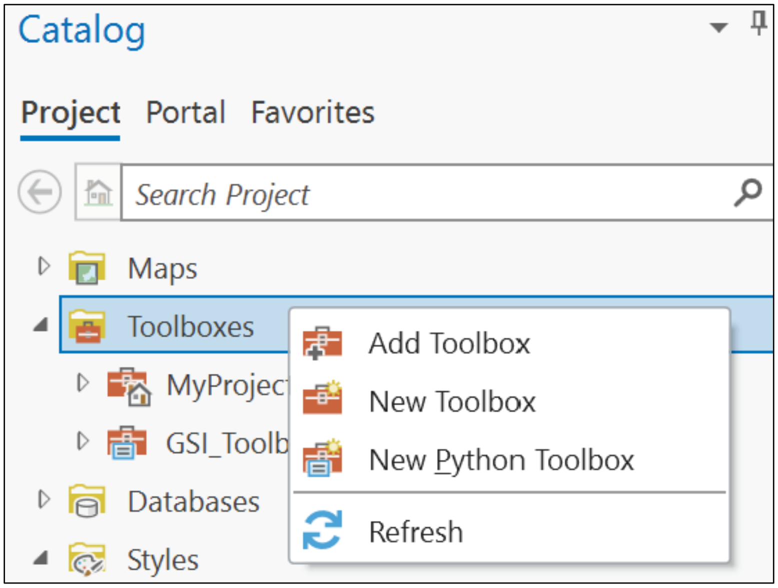
* For a full list of the spelled-out forms of the units of measure used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 248–52, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

Figure 2. Add the GSI toolbox in ArcGIS Pro.



4 Suitability Index Calculator (SIC) Tool

The SIC tool uses thematic or continuous geospatial raster layers representing the spatial variation of the input parameters such as elevation, precipitation, and vegetation cover to calculate parameter suitability indices using suitability rankings defining the species-habitat relationship. The tool assists the user with clipping input data sets to a location of interest (LOI) polygon. Then user-defined or predefined suitability curve values (compiled by McKay and Hernández-Abrams 2020 and available in tabular format from the `SuitabilityTable` folder*) are used to recode parameter data values to numeric values ranging from 0.0 to 1.0, where zero (0) is nonsuitable habitat and one (1) is the most suitable. The output is stored as a floating-point raster in the user-selected spatial reference. While only one parameter suitability index raster can be generated through each tool run, the goal of this tool is to create multiple parameter index raster files that can then be combined using the OSIC tool (described in Section 5) to produce a raster file showing the quantitative habitat assessment for the area and species of interest.

The following subsections describe the tool's data inputs, including required and acceptable file formats. Tool workflow is detailed in two parts according to parameter input data types: (1) thematic data and (2) continuous data. Troubleshooting guidance is included to assist the user when errors occur.

4.1 Data inputs

Three distinct data input files are required for running the SIC tool: a location of interest (LOI) polygon, a thematic or continuous raster file, and a CSV file containing data values and the associated suitability-index values used to map parameter data values. Each input is described below.

4.1.1 Location of interest (LOI) polygon

The LOI represents the spatial extent of the analysis area provided as an Esri polygon shapefile or geodatabase polygon feature layer. The LOI file must have a defined spatial reference, and the tool will use all polygon features in the data set unless selected in the ArcGIS Pro data frame prior

* Suitability data may also be obtained through the *ecorest* package in the R statistical software: https://cran.r-project.org/web/packages/ecorest/index.html.

to running the tool. The SIC tool uses this polygon to clip the input-raster parameter data file. The polygon must fall within the extent of the raster image, or the user will receive an error prior to running the tool. Potential sources of LOIs to consider include USACE project impact areas and alternatives; US county and city boundaries; US Geological Survey (USGS) 8-, 10-, or 12-digit hydrologic unit codes (HUCs) (https://www.usgs.gov/core-science-systems/ngp/national-hydrography/access-national-hydrography-products); and other downloadable data through geospatial websites such as Data.gov (https://catalog.data.gov), The National Map (https://apps.nationalmap.gov/downloader/https://viewer.nationalmap.gov/basic/), and Geospatial Data Gateway (https://gdg.sc.egov.usda.gov/GDGHome_DirectDownLoad.aspx).

NOTE: ALL polygon features in the shapefile will be used in the analysis. Create a single-feature polygon layer if only one polygon is desired.

IMPORTANT: The same LOI input polygon should be used for iterative tool runs that generate parameter suitability index rasters intended as input into the OSIC tool.

4.1.2 Thematic-raster parameter input

Thematic-raster parameter data include categorical geospatial data in a raster file format that is descriptive (for example, vegetation type). All raster file formats supported by ArcGIS Pro (that is, geotiff, img, dat, ESRI GRID) are accepted as input. The data file must have a defined map projection and datum prior to input into the tool. Also, a raster-attribute table containing descriptive data values is highly recommended but not necessary. Potential sources of freely available thematic-raster data include the National Land Cover Database (https://www.mrlc.gov/data; Multi-Resolution Land Characteristics Consortium) and LANDFIRE Vegetation Cover and Vegetation Disturbance Severity (https://www.landfire.gov/).

4.1.3 Continuous-raster parameter input

Continuous-raster parameter data include geospatial data in a raster file format that contains continuous value ranges in an integer or floating-point data type (for example, elevation and precipitation). All raster file formats supported by ArcGIS Pro (that is, geotiff, img, dat, ESRI GRID) are accepted as input. Potential sources of freely available continuous-raster data include USGS digital elevation models (DEMs); LANDFIRE program aspect, elevation, slope (https://www.landfire.gov/); and Esri Open Hub (https://hub.arcgis.com/search).

4.1.4 Species suitability-index values in tabular comma-separated values (CSV) format

Suitability indices are a set of values that define the relationship between a parameter (that is, variable) and its suitability to support a species or habitat community. These values are commonly expressed in graphical form as a curve or graph (Figure 3). However, to use these values in the tool, they must first be formatted into the CSV tabular file format by the user and should be developed using science-based sources such as peer-reviewed journals, expert-opinion, or existing USACE-certified models. The CSV file format must contain at least two fields and three rows. One field should include the parameter values as either text for thematic data or numeric for continuous data. The second field should contain the associated suitability-index values represented as floating-point numbers. The two-field pair describes the parameter value–suitability index relationship by row. The first row must contain a header name, while the remaining rows will contain the graph values as shown in Figure 3.

Guidelines for converting graph (thematic) versus curve (continuous) data are provided in the following examples. For thematic data, a hypothetical suitability graph using the vegetation habitat classes is provided (Figure 3, *top*). Each class in the graph displays a specific suitability-index value. Therefore, a CSV table is created containing two fields with the headings `veg.class` and `veg.class.SIV`. Next, values are added to each row in the table with the class name (that is, *Agriculture* under the `veg.class` heading) and associated suitability-index value (that is, *0.25* under the `veg.class.SIV` heading). For a continuous data, a hypothetical suitability curve for elevation is provided (Figure 3, *middle*). Each break point in the curve represents a specific suitability-index value, and at least two break points are required. Then, a CSV table is created containing two fields, with the headings `elevation.m.class` and `elevation.m.SIV`. Next, break point values are added to each row in the table with the elevation value (that is, *50* under the `elevation.m.class` heading) and associated suitability-index value (that is, *0.20* under the `elevation.m.SIV` heading).

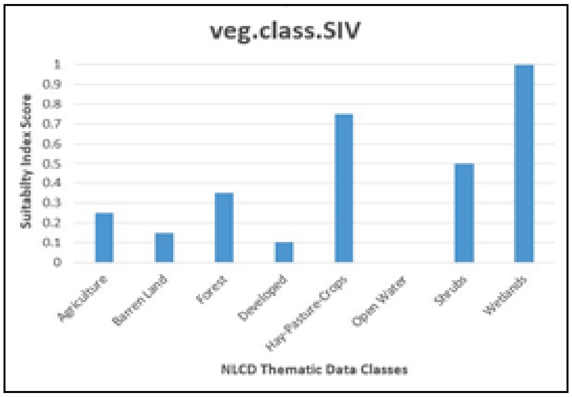
The species suitability-index data table, stored in a CSV tabular file format, is used to recode input-raster parameter data values to suitability-index values. Details on how the tool uses this table to calculate parameter suitability index rasters is provided in Sections 4.2.1 and 4.3.1.

Preformatted data tables are also provided with the toolbox zip file in the `SuitabilityTables` folder. The CSV tables included with the toolbox were generated as part of the ERDC *ecorest* package (McKay and Hernández-Abrams 2020).

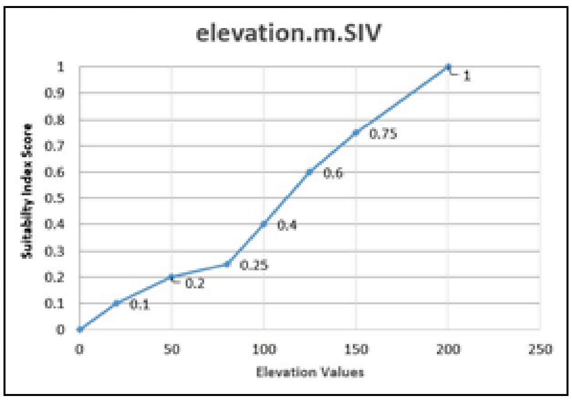
IMPORTANT: Input parameter raster values must be in the same measurement units (that is, meters, parts per thousand) and data type (that is, text, integer, floating point) as the suitability-index table data values.

NOTE: While multiple paired field values can be present in the CSV file, there only exists a relationship between parameter pairs (that is, `veg.class` and `veg.class.SIV`).

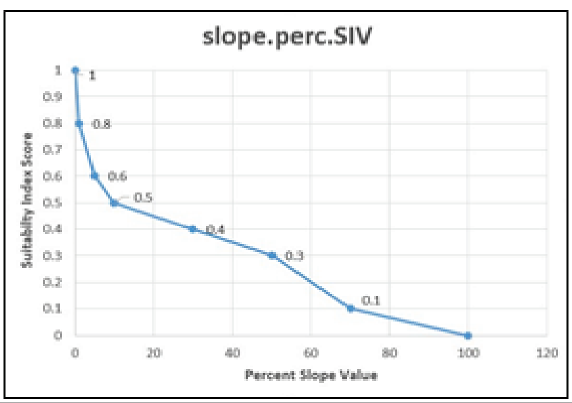
Figure 3. Example of how to format a CSV table (*right*) from habitat-suitability curves or graphs (*left*) prior to use in the tool. A sample CSV file is included with the tool download in the `SuitabilityTables` folder (`SpeciesHSITable.csv`). *Top* graph and table provide a thematic-data example, while the *middle* and *bottom* graphs and tables represent continuous-data examples.



veg.class	veg.class.SIV
Agriculture	0.25
Barren Land	0.15
Forest	0.35
Developed	0.10
Hay-Pasture	0.75
Open Water	0.00
Shrubs	0.50
Wetlands	1.00



elevation.m	elevation.m.SIV
0	0.00
20	0.10
50	0.20
80	0.25
100	0.40
125	0.60
150	0.75
200	1.00



slope.perc	slope.perc.SIV
0	1.00
1	0.80
5	0.60
10	0.50
30	0.40
50	0.30
70	0.10
100	0.00

4.2 Thematic-raster parameter workflow

4.2.1 Workflow description

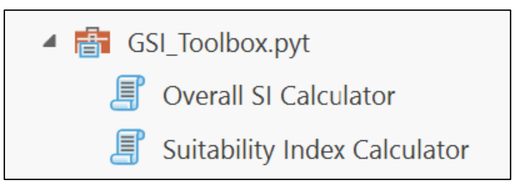
Thematic- or categorical-raster data such as land-cover types are qualitative or descriptive data with distinct classes defining parameter features. The tool allows the user to recode these discrete classes into suitability-index values using CSV file input by matching unique class values to the data values in the CSV file through a dialog box selection process. The output file is a floating-point raster with suitability-index values assigned to each class on a scale from 0.0 to 1.0, where zero (0) is nonsuitable habitat and one (1) is the most suitable.

NOTE: Although the entry for some inputs are shown as optional, the input is required when a green dot is shown adjacent to the input text. The *(optional)* notation is an artifact of Esri's Python toolbox standards.

4.2.2 Workflow guide

To initialize the tool, double-click the Suitability Index Calculator menu option under the GSI toolbox as shown in Figure 4. The *red numbered steps* shown in Figure 5 correspond to the steps below and will guide the user through the tool workflow using a hypothetical example of the Bayou Sara, Louisiana, hydrologic unit. The following files downloaded with the initial installation (Section 3.3) will be used as part of this exercise: LOI shapefile (`../SampleData/HypotheticalExample/BayouSara_HUC10.shp`), CSV table (`../SuitabilityTables/SpeciesHSITable.csv`), and thematic raster (`../SampleData/HypotheticalExample/NLCD2016.img`).

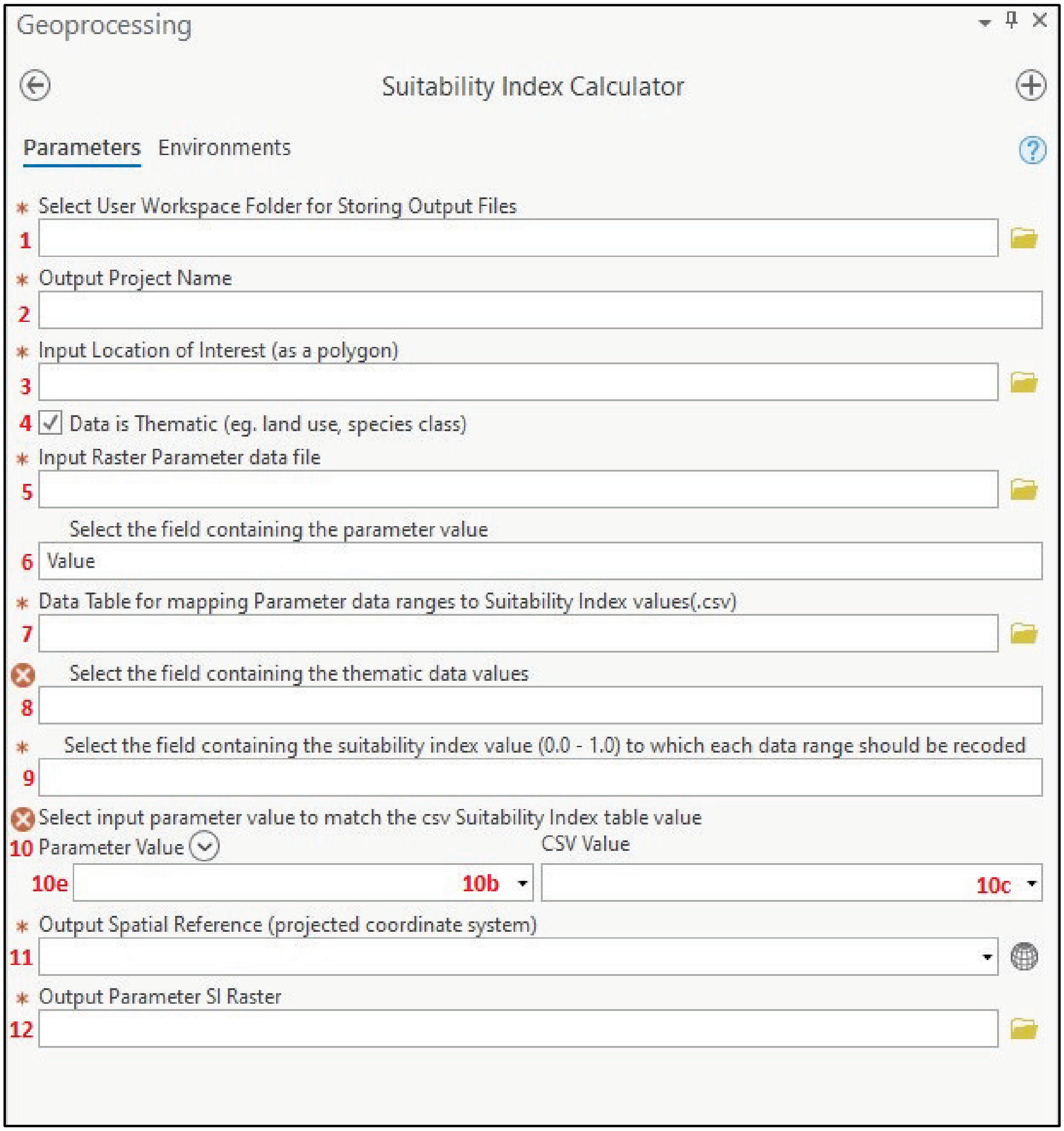
Figure 4. Suitability index calculator (SIC) tool.



NOTE: To use thematic-raster data in the tool, you must select the checkbox option Data is Thematic.

IMPORTANT: If the user plans to develop multiple parameter suitability indices for input in the OSIC tool (described in Section 5), all input-raster files must have matching pixel spatial resolution (that is, cell size); spatial extent (that is, clipped to same LOI); and spatial reference.

Figure 5. The SIC tool's dialog box for thematic data. The *red numbers* correspond to the numbered steps in the workflow.



4.2.3 Step-by-step workflow

1. Select User Workspace Folder for Storing Output Files
   a. Using the Folder icon, browse to the directory where the output file geodatabase will be created to store all intermediate files created by the tool.
   b. If the folder does not already exist, a new folder can be created by selecting the New Folder icon from the New Items pull-down menu in the dialog box.

2. Output Project Name
   a. The project name is a descriptive name that will be added as a prefix to the file geodatabase automatically created by the tool to store output files (for example, `ProjectAreagsi.gdb`). This name is used to allow the user to distinguish between multiple file runs and to avoid overwriting existing files.

> NOTE: all spaces and special characters will be automatically removed from the project name entered.
>
> ERROR MESSAGE: An error message will appear if the name already exists.

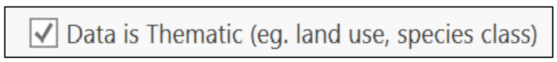
3. Input Location of Interest (as a polygon)
   a. The LOI as defined by the user can be either an Esri polygon shapefile or a geodatabase polygon feature layer. In the `SampleData` folder provided in the `GSI_Toolbox.zip`, select the `BayouSara_HUC10.shp` file. The tool will use all polygons features in the file.
   b. The polygon LOI will be stored in the workspace as defined in Step 1 and used to clip the parameter raster. It will also serve as the spatial extent for analysis.

> NOTE: Be aware that the same LOI input polygon should be used for iterative tool runs that generate parameter suitability index rasters intended as input into the OSIC tool.

> ERROR MESSAGE: The polygon must fall within the extent of the raster image, or the user will receive an error prior to running the tool.

4. Checkbox for Data is Thematic
    a. Checkbox must be selected if raster parameter data are thematic (descriptive such as land cover). For the thematic workflow demonstration provided here, the box must be checked (Figure 6).

Figure 6. Data is Thematic checkbox.



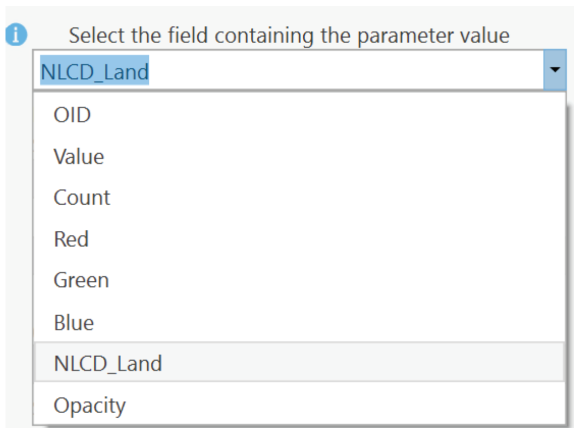
5. Input Raster Parameter data file
    a. Using the Folder icon, navigate to the directory where the thematic-raster file is stored. The file may be in any raster format accepted by ArcGIS Pro (that is, geotiff, img, dat, ESRI GRID). The file cannot be in a floating-point raster data type. In the `SampleData/HypotheticalExample` folder provided in the `GSI_Toolbox.zip`, select the raster `NLCD2016.img`.

> NOTE: For iterative SIC tool runs intended as input into the OSIC tool, all raster data should have the same pixel resolution (that is, cell size); spatial extent (that is, clipped to the same LOI); and spatial reference.
>
> ERROR MESSAGE: If an error is displayed, the spatial extent of the LOI polygon does not fit within the spatial extent of the raster input. Select an LOI polygon that is within the spatial extent of the raster parameter file.

6. Select the field containing the parameter attribute value
    a. This input is enabled when the Data is Thematic checkbox is selected. Although the entry is shown as optional, the input is required when using thematic parameter data. The “(optional)” notation is an artifact of Esri Python toolbox coding requirements.

b. From the pull-down menu, choose the field (`NLCD_Land`) in the thematic-raster attribute table containing the unique class values from the raster. This step will set up the parameter raster attribute field necessary for matching the data values in the CSV suitability-index table through the selection dialog box described in Step 10 (Figure 7).

Figure 7. The SIC tool parameter input to select the field within the thematic data set that contains the parameter value.



7. Input data Table for mapping Parameter data ranges to Suitability Index Values(.csv)

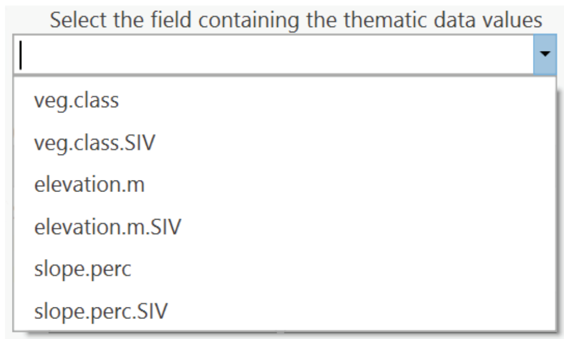
   a. The purpose of the suitability index data table is to recode the parameter raster attribute class values from the raster file to suitability-index values. The tool only accepts tables in a CSV file format. For CSV file formatting, please refer to Section 4.1 and Figure 3. The table can be provided as either user-defined or selected from the predefined suitability-index tables provided with the installation files and located in the `SuitabilityTables` folder.
   b. Click the Folder icon and navigate to the CSV table (in the `SuitabilityTables` folder provided in the `GSI_Toolbox.zip`, select the CSV file `SpeciesHSITable.csv`) and click the OK button.

8. Select the field containing the thematic data values

   a. The thematic data value field is a text or integer value field in the CSV table (for example, `SpeciesHSITable.csv`) that contains the unique thematic data values for matching to the parameter raster attribute class values. This step will set up the data field necessary for matching through the selection dialog box described in Step 10.

b. Select the field from the pull-down menu (`veg.class`). The list corresponds to the unique field names in the CSV table selected in Step 7 (Figure 8).

Figure 8. SIC tool parameter input to select the thematic value field from the CSV file that contains the thematic data values.

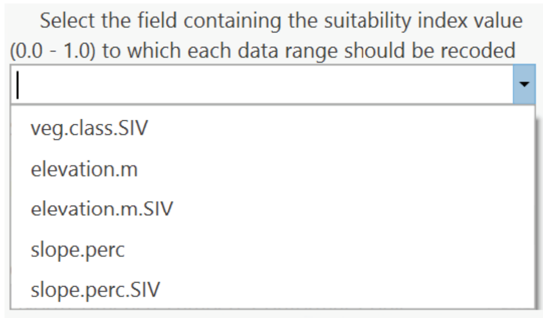


c. This input is enabled when the Data is Thematic checkbox is selected. Although the entry is shown as optional, the input is required when using thematic parameter data. The “(optional)” notation is an artifact of the Esri Python toolbox coding requirements.

9. Select the field containing the suitability-index value (0.0 - 1.0) to which each data range should be recoded

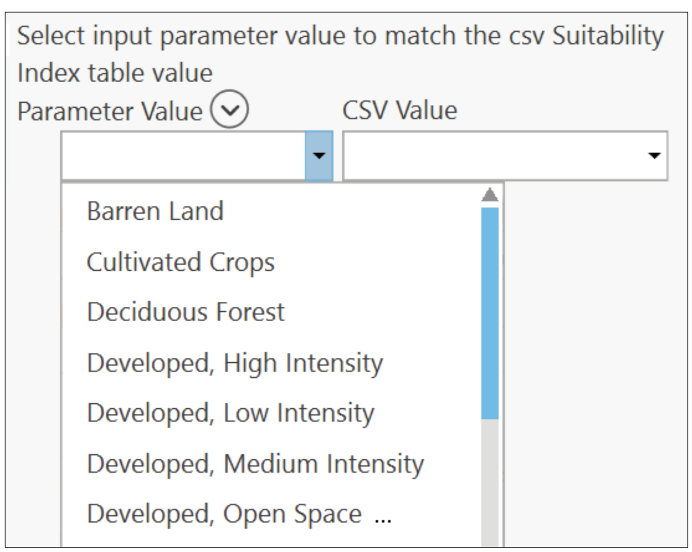
   a. The suitability-index field must contain the suitability-index values as a floating-point number from zero to one (0.0–1.0) that represents the suitability for each data value provided in the CSV table (for example, `SpeciesHSITable.csv`). This step will set up the suitability-index field necessary for matching through the selection dialog box described in Step 10.
   b. Select the field from the pull-down menu (`veg.class.SIV`). The list represents the unique field names in the CSV table selected in Step 7 (Figure 9).

Figure 9. SIC tool parameter input to select the suitability index value field from the CSV file that contains the thematic data values.



10. Select input raster parameter value to match the CSV Suitability Index table value
    a. With the fields selected in Steps 6, 8, and 9, the parameter attribute matching to suitability-index values is ready for selection using the dialog box.
    b. First, select the Parameter Value from the pull-down list (Figure 10). This list displays all unique values of the parameter raster attribute field chosen in Step 6. After selection, the value will be populated under the Parameter Value heading in the table dialog box.

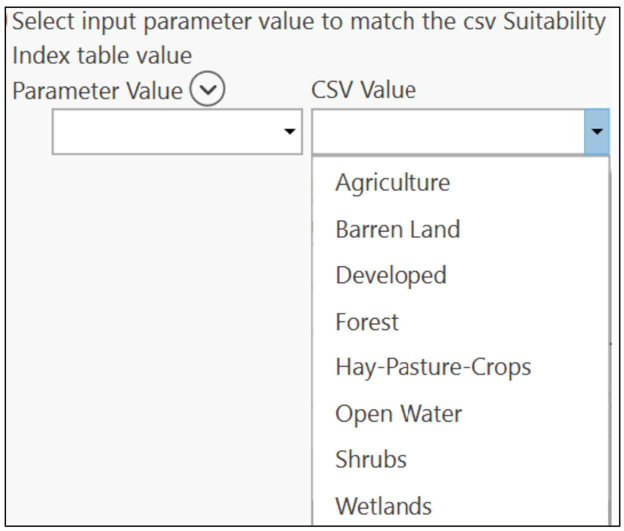
Figure 10. SIC tool parameter input for selecting the thematic value based on the unique values.



NOTE: An error will be displayed temporarily until the CSV Value is selected.

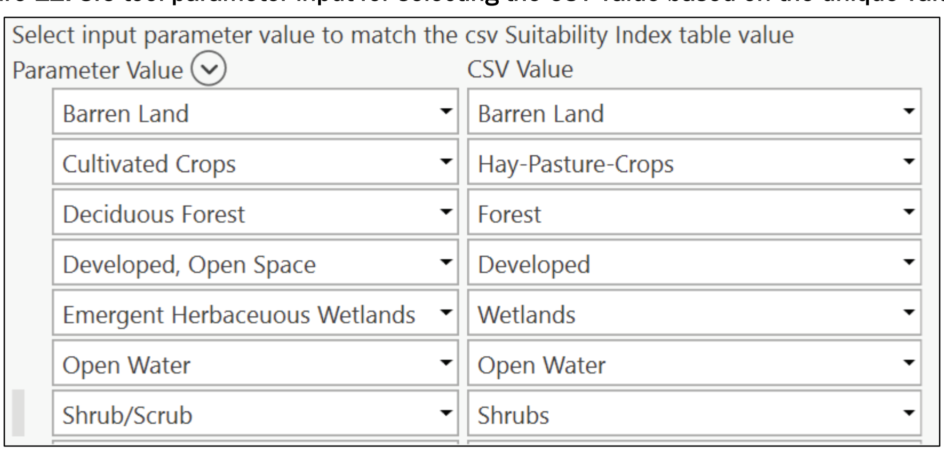
c. Next, click in the empty cell adjacent to the Parameter Value under the heading CSV Value. Using the drop-down arrow, select the desired data value to match the one displayed under the Parameter Value heading and row (Figure 11). The CSV Value list displays all unique values in the data field chosen in Step 8.

Figure 11. SIC tool parameter input for selecting the CSV value based on the unique values.



d. Repeat this process for each Parameter and CSV Value desired (Figure 12).

Figure 12. SIC tool parameter input for selecting the CSV value based on the unique values.



e. To remove unwanted values, hover over the area to the left of the row and choose the red X button to delete.

f. This input is enabled when the Data is Thematic checkbox is selected. Although the entry is shown as optional, the input is required when using thematic parameter data. The “(optional)” notation is an artifact of the Esri Python toolbox coding requirements.

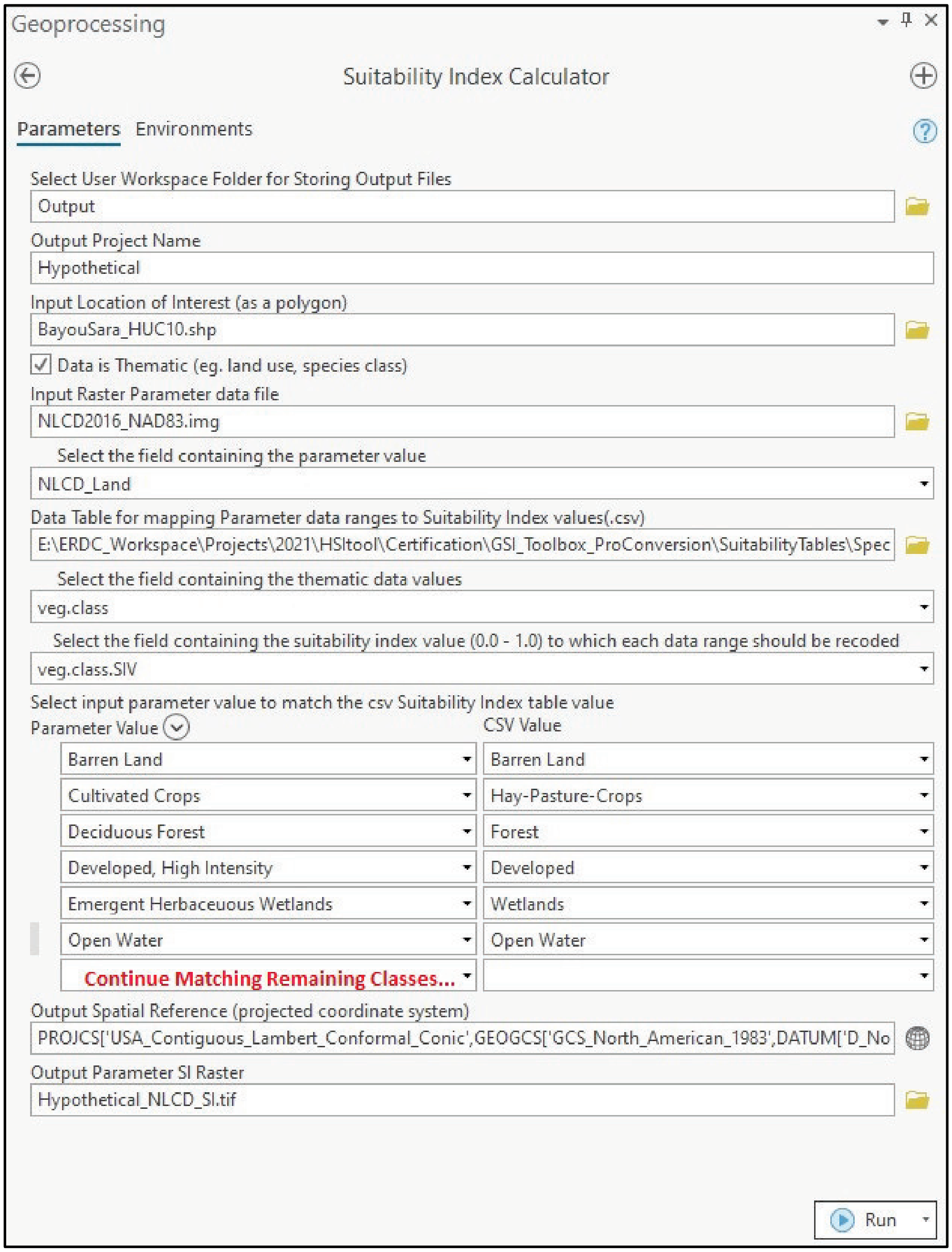
11. Output Spatial Reference (projected coordinate system)
    a. Select the button on the right to define the Spatial Reference for all output data. For more information on Map projections used in ArcGIS, please refer to Kennedy and Kopp (2001).

12. Output Parameter SI Raster
    a. Using the Folder icon, navigate to the directory where the thematic-raster suitability-index file will be stored (Figure 5). The file can be stored in any raster format accepted by ArcGIS Pro (that is, geotiff, img, dat, ESRI GRID). The extension should be added to the filename, or an ESRI GRID will automatically be created as output. The output file will be a floating-point raster data type with a data range of 0.0–1.0.

WARNING: Existing files with the same name will be overwritten. The tool will give a warning prior to the tool run if the file already exists.

    b. The SIC tool dialog box will appear as shown in Figure 13 below.

Figure 13. The Suitability Index Calculator tool's dialog box for a hypothetical data example of thematic data input.

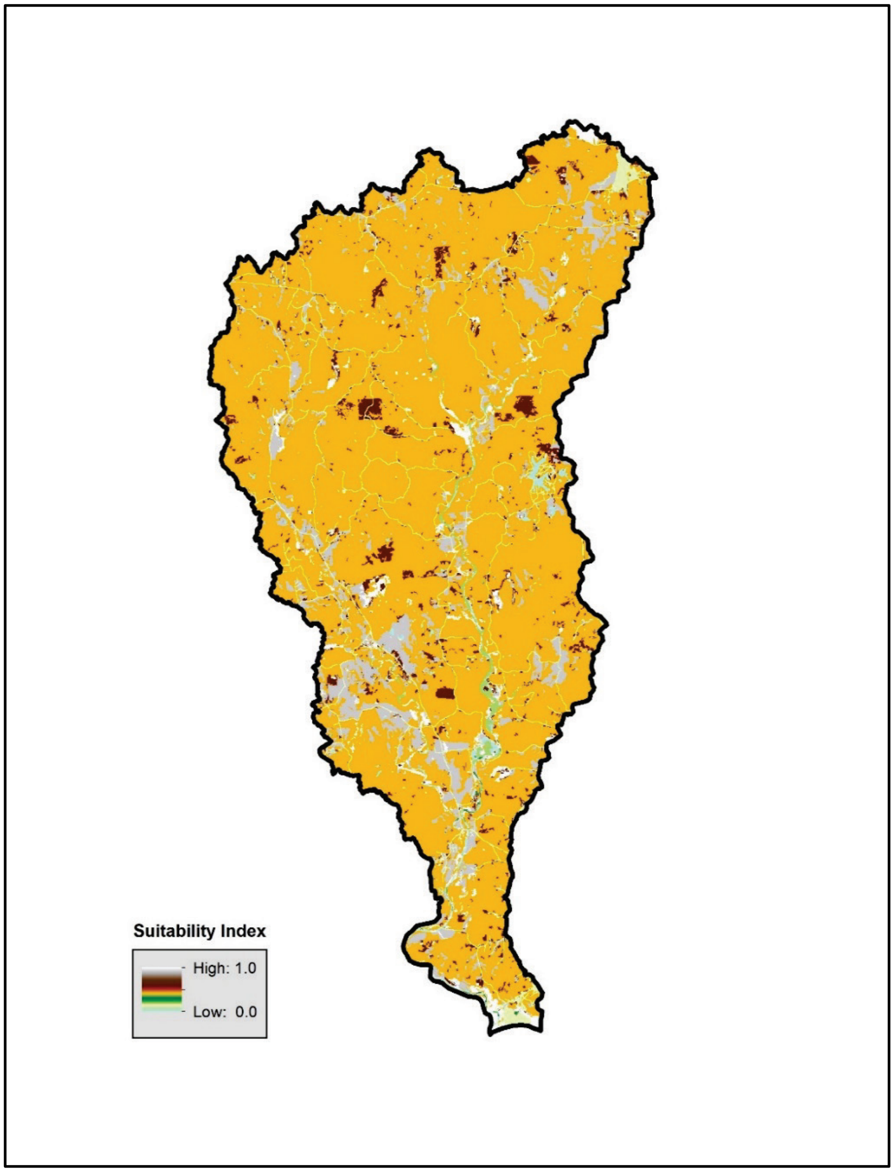


13. To run the tool, click the Run button at the bottom right of the dialog box.

NOTE: Be cognizant that all raster output generated by iterative tool runs and intended as input into the OSIC tool should have the same pixel resolution, spatial extent, and spatial reference. For information on how to resample raster images to the appropriate pixel resolution, please refer to ArcGIS Resample tool help documentation.

14. Examples of the results are provided in the folder `../SampleData/Results/Hypothetical_NLCD_SI.tif` and shown in Figure 14.

Figure 14. Hypothetical thematic suitability-index raster output from the SIC tool using the National Land Cover Database for Bayou Sara, Louisiana, hydrologic unit code (HUC).



4.3 Continuous-raster parameter workflow

4.3.1 Workflow description

Continuous-raster data are data that represent earth features and processes as a continuous range of values, such as elevation. A stepwise implementation of the linear-regression formula for continuous data is used to recode input values into suitability-index scores using the data values and associated suitability-index value ranges provided in the suitability tables (CSV file). The appropriate suitability-index values are assigned to each class on a scale from 0.0 to 1.0, where zero (0) is nonsuitable habitat and one (1) is the most suitable. First, the model sorts the CSV table by the user-selected data field in ascending order. Then, the data values and associated suitability-index values from the first two rows of the table are used to calculate the slope of the line, y-intercept, and linear-regression formula. If more than two rows are present in the CSV table, the model will advance one row down and apply the formulas to the second and third rows, then third and fourth rows, and so on until no data values remain.

NOTE: Although the entry for some inputs are shown as optional, the input is required when a green dot is shown adjacent to the input text. The "(optional)" notation is an artifact of Esri's Python toolbox standards.

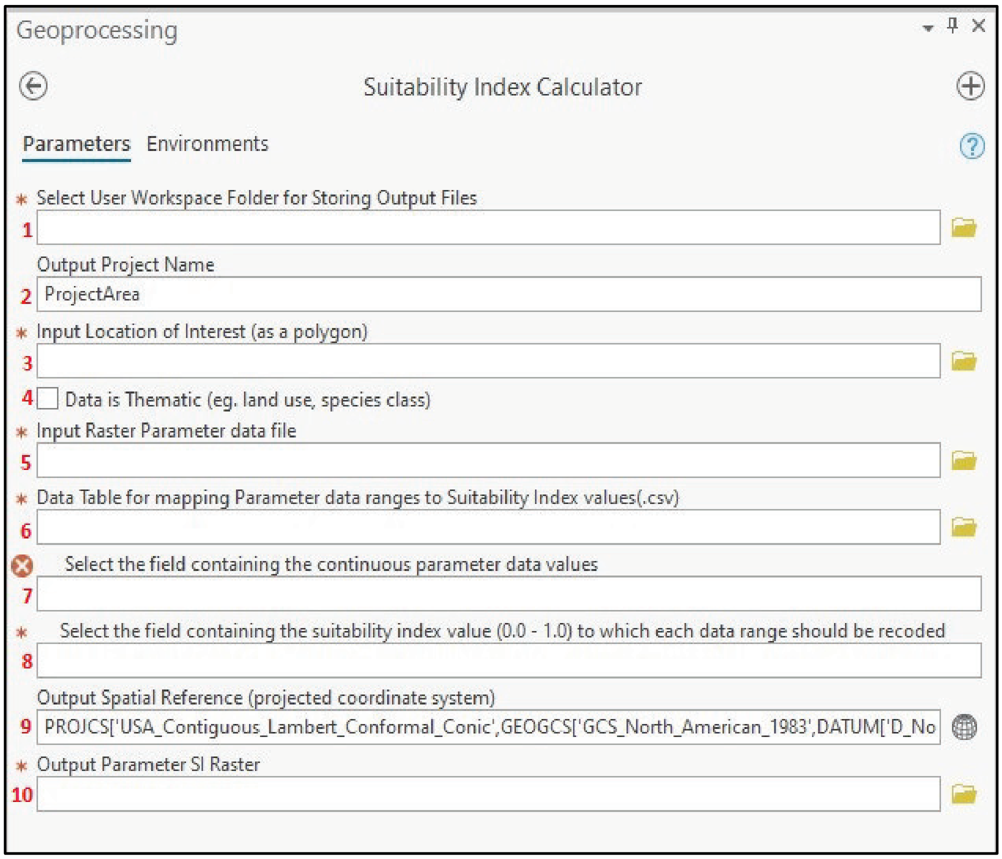
The slope and intercepts of the line (β_1 and β_0, respectively) and representative *Y* values are calculated using Equations (1), (2), and (3), described in Section 2.2.2. Inputs are provided via the suitability-index table in the CSV input file, where x_1 is the first data point value, x_2 is the second data point value, y_1 is the first suitability-index score, and y_2 is the second suitability-index score.

4.3.2 Workflow guide

To initialize the tool, double-click the SIC tool under the GSI toolbox as shown in Figure 4. The *red numbered steps* shown in Figure 15 correspond to the steps below and will guide the user through the tool workflow using a hypothetical example of the Bayou Sara, Louisiana, hydrologic unit. The following files downloaded with the initial installation (Section 3.3) will be used as part of this exercise: LOI shapefile

(`../SampleData/HypotheticalExample/BayouSara_HUC10.shp`), CSV table (`../SuitabilityTables/SpeciesHSITable.csv`), and continuous rasters (`../SampleData/HypotheticalExample/LANDFIRE2016_DEM.tif`) and (`../SampleData/HypotheticalExample/LANDFIRE2010_Slope.tif`). These steps will guide the user through the tool workflow using continuous-raster data.

Figure 15. SIC tool dialog box input description for continuous data. The *red numbers* correspond to the numbered steps described in the workflow.



4.3.3 Step-by-step workflow

1. Select User Workspace Folder for Storing Output Files
   a. Using the Folder icon, browse to the directory where a file geodatabase will be created to store all intermediate files created by the tool.
   b. If the folder does not already exist, a new folder can be created by selecting the New Folder icon from the New Items pull-down menu in the dialog box.

2. Output Project Name
   a. The project name is a descriptive name that will be added as a prefix to the file geodatabase automatically created by the tool to store output files (for example, `ProjectAreagsi.gdb`). This name is used to allow the user to distinguish between multiple file runs and to avoid overwriting existing files.

NOTE: all spaces and special characters will be automatically removed from the project name entered.

ERROR MESSAGE: An error message will appear if the geodatabase already exists.

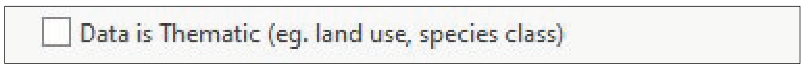
3. Input Location of Interest (as a polygon)
   a. The LOI as defined by the user can be either an Esri polygon shapefile or a geodatabase polygon feature layer. In the `SampleData` folder provided in the `GSI_Toolbox.zip`, select the `BayouSara_HUC10.shp` file. The tool will use all polygon features in the file.
   b. The resulting LOI polygon will be stored in the workspace as defined in Step 1 and used throughout the tool analysis as the spatial extent.

NOTE: Be aware that the same LOI input polygon should be used for iterative tool runs that generate parameter suitability index rasters intended as input into the OSIC tool.

ERROR MESSAGE: The polygon must fall within the extent of the raster image, or the user will receive an error prior to running the tool.

4. Checkbox for Data is Thematic should remain **unchecked** for continuous-raster input (Figure 16).

Figure 16. Data is Thematic checkbox unchecked.



5. Input Raster Parameter data file
   a. Using the Folder icon, navigate to the directory where the thematic-raster file is stored. The file may be in any raster format accepted by ArcGIS Pro (that is, geotiff, img, dat, ESRI GRID). The file cannot be in a floating-point raster data type. In the `SampleData/HypotheticalExample` folder provided in the `GSI_Toolbox.zip`, select the raster `LANDFIRE2016_DEM.tif`.

NOTE: For iterative SIC tool runs intended as input into the OSIC tool, all raster data should have the same pixel resolution (that is, cell size); spatial extext (that is, clipped to LOI); and spatial reference.

ERROR MESSAGE: If an error is displayed, the spatial extent of the LOI polygon does not fit within the spatial extent of the raster input. Select an LOI polygon that is within the spatial extent of the raster parameter file.

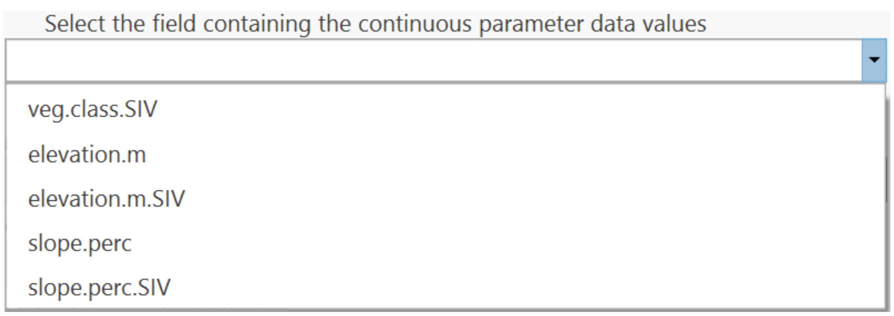
6. Data Table for recoding Parameter data ranges to Suitability Index values(.csv)
   a. The purpose of the suitability-index data table is to recode the parameter raster data values from the raster file to suitability-index values. The tool only accepts tables in a CSV file format. For CSV file formatting, please refer to Section 4.1 and Figure 3. The table can be provided as either user-defined or selected from the predefined suitability-index tables provided with the installation files and located in the `SuitabilityTables` folder.

   b. Click the Folder icon and navigate to the CSV table (In the `SuitabilityTables` folder provided in the `GSI_Toolbox.zip`, select the CSV file (`SpeciesHSITable.csv`) and click the OK button.

7. Select the field containing the continuous parameter data value

   a. The Continuous Data Value is a floating-point or integer value field in the data table that contains the data values for matching to the parameter raster data values and converting them to suitability-index values. Select the field from the pull-down menu (`elevation.m`). The list corresponds to the unique field names in the CSV table (`SpeciesHSITable.csv`) selected in Step 6 (Figure 17).

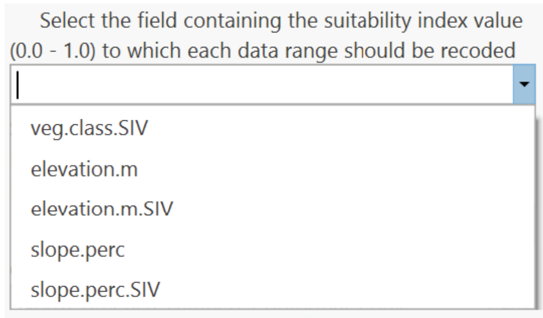
Figure 17. SIC tool parameter input to select the field from the CSV file that contains the continuous data values.



8. Select the field containing the suitability index value (0.0 - 1.0) to which each data range should be mapped

   a. Suitability-index field will contain the suitability-index values as a floating-point number from zero to one (0.0–1.0) that represents the suitability for each data value provided.
   b. Select the field from the pull-down menu (`elevation.m.SIV`). The list represents the unique field names in the CSV table (`SpeciesHSITable.csv`) selected in Step 7 (Figure 18).

Figure 18. SIC tool parameter input to select the field from the CSV file that contains the continuous data values.

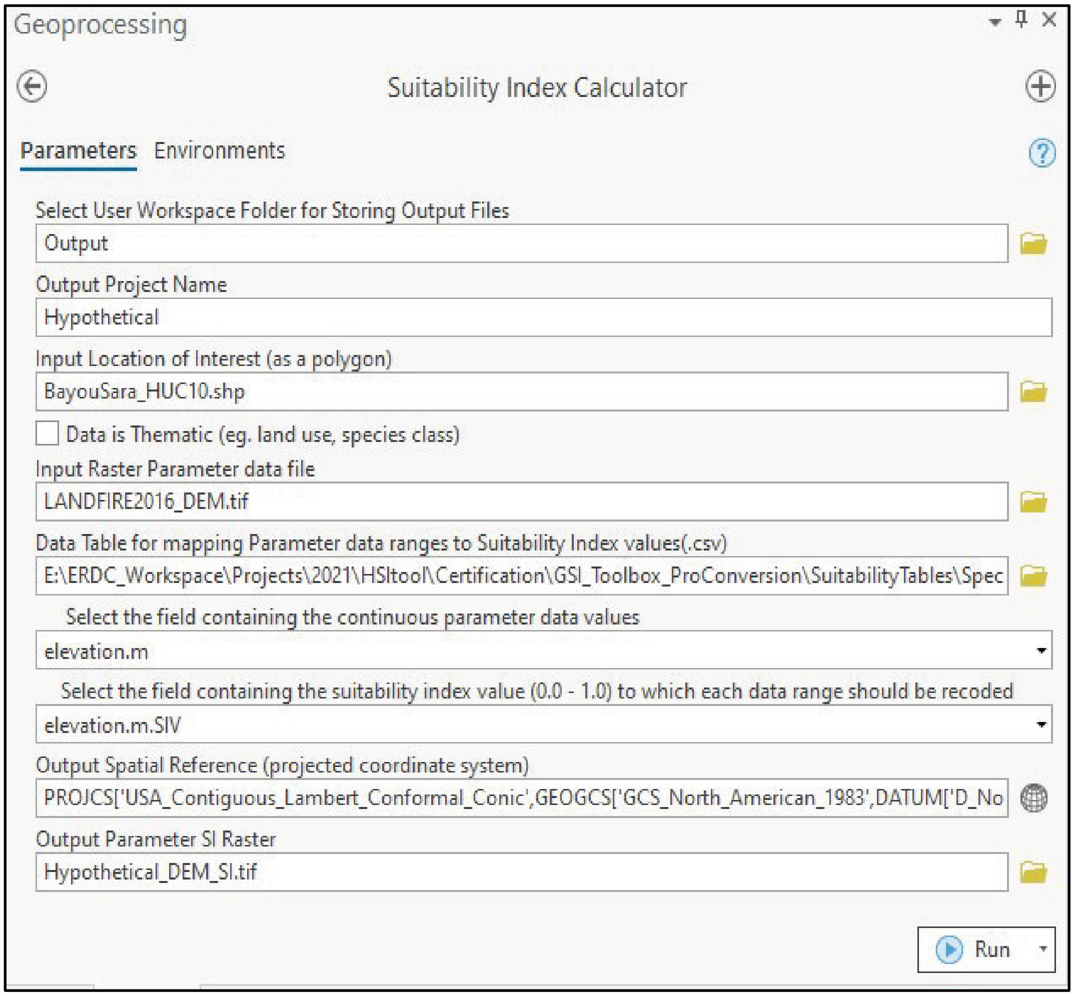


9. Output Spatial Reference (projected coordinate system)
    a. Select the button on the right to define the Spatial Reference for all output data. For more information on Map projections utilized in ArcGIS, please refer to Kennedy and Kopp (2001).

10. Output Parameter SI Raster
    a. Using the folder icon , navigate to the directory where the continuous raster suitability index file will be stored. The file can be stored in any raster format accepted by ArcGIS Pro (that is, geotiff, img, dat, ESRI GRID). The extension should be added to the filename or an ESRI GRID will automatically be created as output. The output file will be a floating-point raster data type with a data range of 0.0–1.0 (Figure 19).

WARNING: Existing files with the same name will be overwritten. The tool will give a warning prior to the tool run if the file already exists.

Figure 19. The Suitability Index Calculator tool's dialog box for a hypothetical example of continuous data input.



11. To run the tool, click the Run button at the bottom right of the dialog box.

NOTE: Be cognizant that all raster output generated by iterative tool runs and intended as input into the OSIC tool should have the same pixel resolution and spatial reference. For information on how to resample raster images to the appropriate pixel resolution, please refer to ArcGIS Resample tool help documentation.

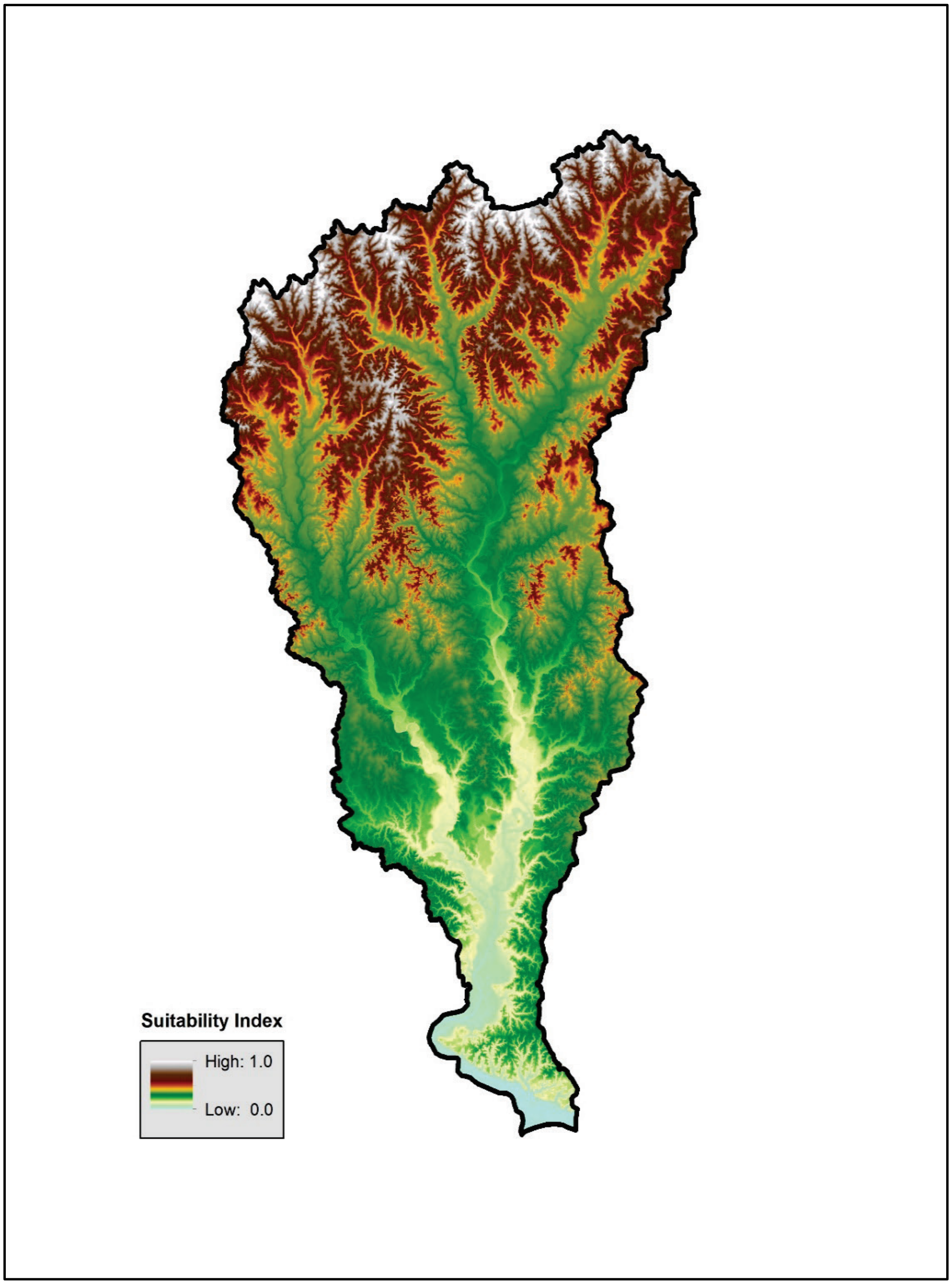
12. In preparation for developing the overall suitability index workflow detailed in Section 5, the user should repeat Steps 1–11 above using the continuous slope raster (`../SampleData/HypotheticalExample/LANDFIRE2010_Slope.tif`) as input into Step 5. The raster was downloaded with the initial installation

as described in Section 3.3. Within the `SpeciesHSITable.csv` table, the user should also select (`slope.perc`) field in Step 7 and (`slope.perc.SIV`) field in Step 8.

ERROR CHECK: If the tool runs but no output is produced, please make sure that the parameter raster data type (integer or floating point) is the same data type as the data value in the CSV file. Adjust accordingly. Also, ensure that the checkbox for Data is Categorical in unchecked.

13. Examples of the results are provided in the folder (`../SampleData/Results/Hypothetical_DEM_SI.tif`) (Figure 20) and (`..Hypothetical_SLOPE_SI.tif`).

Figure 20. Hypothetical continuous suitability index raster output from the SIC tool using the LANDFIRE digital elevation model (DEM) data set for Bayou Sara, Louisiana, HUC.



5 Overall Suitability Index Calculator (OSIC) Tool

The OSIC is a tool that allows the user to integrate multiple ecosystem parameter suitability indices that define the species-habitat relationship into a single raster layer representing the species' environmental habitat suitability. Four statistical options are available for calculating suitability: AM, WAM, GM, and MLF. When running the tool, at least one option must be selected; however, multiple statistical options are allowed. The output is a floating-point raster representing suitability-index values from 0.0 to 1.0, where zero (0) is nonsuitable habitat and one (1) is the most suitable. In addition, an informational text file is generated describing all input files, the statistical analysis option, assigned weights (if applicable), and the output file name. The text file is stored in the same folder as the output overall suitability index raster and has the same file base name, but with the .txt extension. The following subsections describe data inputs into the tool, including required and acceptable file formats, statistical methodology, tool workflow, and troubleshooting guidance to assist the user when errors occur.

5.1 Data inputs

5.1.1 Parameter suitability index raster

Parameter suitability index raster files representing the species-habitat relationship are represented through a suitability ranking, with data values ranging from 0.0 to 1.0. The SIC tool generates these files as output for use in the OSIC tool. The raster files should be of floating-point data type in a file format supported by ArcGIS Pro (that is, geotiff, img, dat, ESRI GRID). At least two parameter suitability index raster files are required as input into the OSIC tool, and a maximum of ten are allowed. This limit ensures optimal performance of the toolbox and decreased computational time while providing sufficient input necessary for generating overall habitat suitability.

WARNING:All input raster files MUST have the same pixel resolution, spatial extent, and spatial reference to produce accurate calculations of habitat suitability.

5.2 Statistical options

The overall suitability index raster is created by combining the multiple individual parameter suitability index rasters using one or more of the following statistical methods: AM, WAM, GM, and MLF. Each of these methods except MLF are based on central tendency statistics. Therefore, to determine which option would best suit the data, an assessment of the strengths and weaknesses of each method is needed. Each method is described in detail in Section 2.2.2. The AM is a well-known statistic where each parameter suitability index is considered equally important to the overall suitability of the habitat. However, it is sensitive to outlier values and not well suited for calculations where parameters are not of equal importance. The WAM statistic has similar disadvantages relative to AM; however, it is beneficial when individual parameter suitability indices are of varying importance. The GM statistic is less sensitive to outlier values, since it normalizes the value ranges across the multiple parameter suitability indices in the calculation. But zero-value pixels in one parameter suitability index will negate those same pixel locations in all other parameter suitability indices used in the calculation. This statistic could be beneficial if the suitability of habitat depends on all parameter suitability indices. The advantage of MLF, commonly referred to as Liebig's law of the minimum, is its ability to depict the most vulnerable areas in the habitat. However, one disadvantage is that an additional analysis may be needed to determine which parameter caused the limitation.

5.3 OSIC tool workflow

To initialize the OSIC tool, double-click the Overall SI Calculator tool under the GSI toolbox menu as shown in Figure 21. The OSIC tool workflow is described through a series of numbered steps listed below that correspond to the *red numbers* shown on the OSIC tool dialog boxes in Figures 22 and 23. The steps will guide the user through the tool workflow using a hypothetical example of the Bayou Sara, Louisiana, hydrologic unit. The following files downloaded with the initial installation (Section 3.3) will be used as part of this exercise and include three parameter suitability indices within the `../SampleData/HypotheticalExample/Results` folder: `Hypothetical_NLCD_SI.tif` (landcover), `Hypothetical_DEM_SI.tif` (elevation), and `Hypothetical_SLOPE_SI.tif` (percent slope).

Figure 21. Overall Suitability Index Calculator (OSIC) tool.

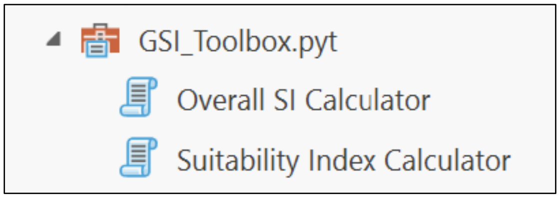
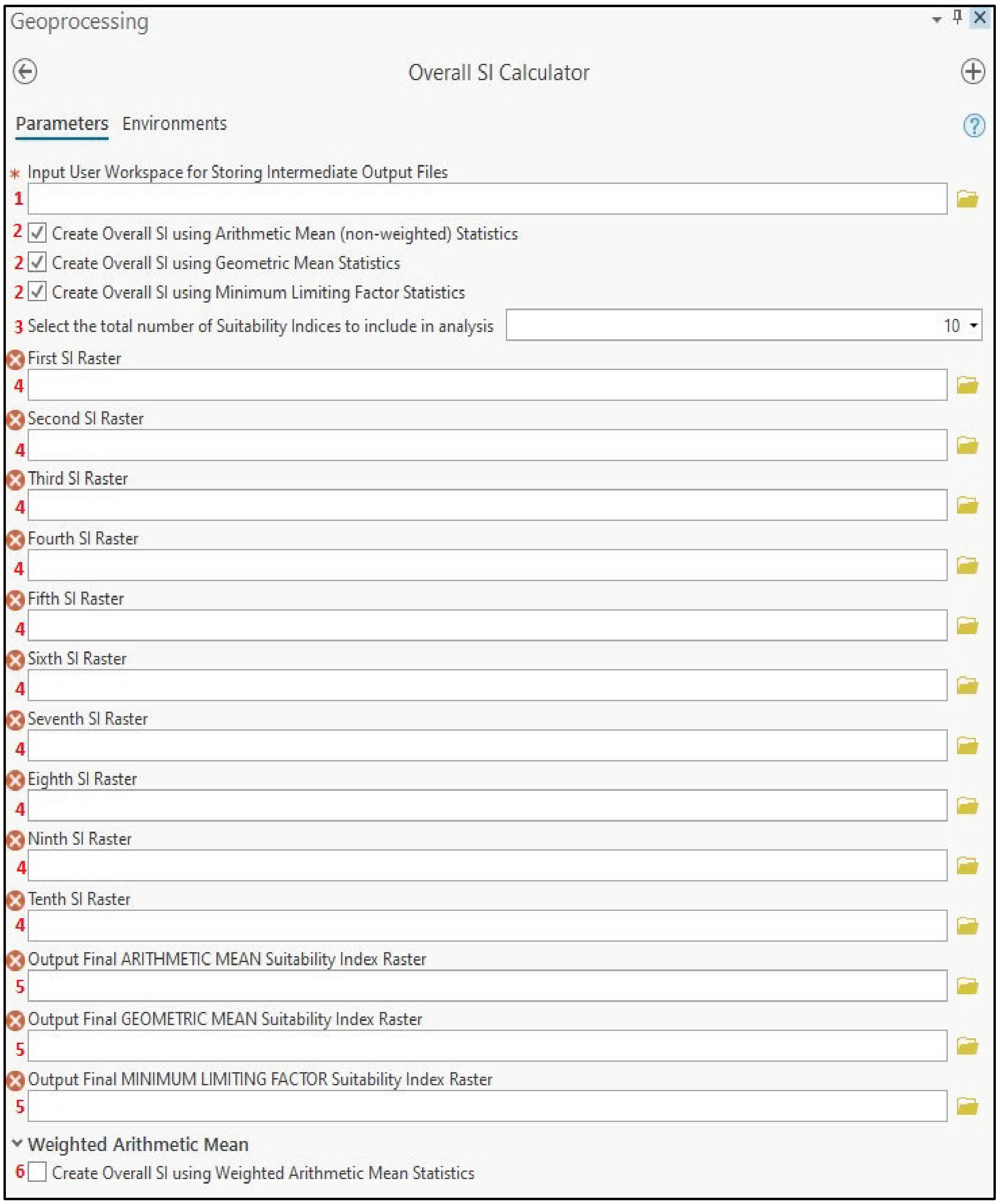


Figure 22. OSIC tool's dialog box input displaying *red numbers* corresponding to the workflow steps.



5.3.1 Step-by-step workflow

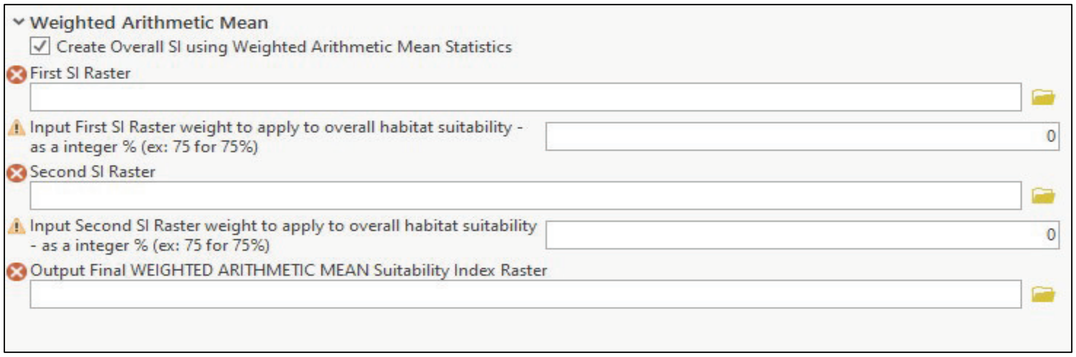
1. Input User Workspace for Storing Intermediate Output Files
   a. Using the Folder icon, browse to the directory where a file geodatabase will be created to store all intermediate files created by the tool.
   b. If the folder does not already exist, a new folder can be created by selecting the New Folder icon from the New Items pull-down menu in the dialog box.

2. Select the statistical method desired for creating the overall suitability index using checkboxes.
   a. Four options are available for selection:
      (1) Create Overall SI using Arithmetic Mean (non-weighted) Statistics
      (2) Create Overall SI using Geometric Mean Statistics
      (3) Create Overall SI using Minimum Limiting Factor Statistics
      (4) Create Overall SI using Weighted Arithmetic Mean Statistics (checkbox located beneath Weighted Arithmetic Mean accordion menu, see Step 2d below)
   b. At least one option must be checked, but up to four selections can be accepted.

NOTE: A caution () will be displayed until at least one option is checked.

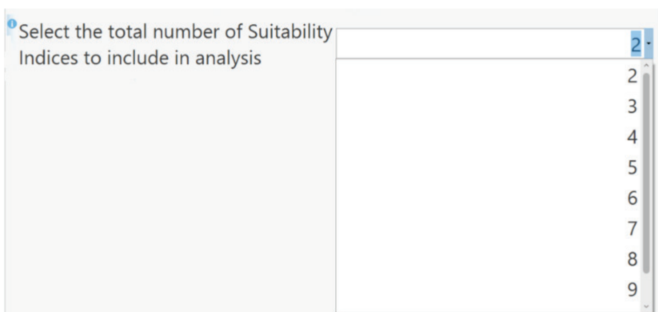
   c. Also note that for each checkbox selected, the Output Final Suitability Raster field will be enabled, as explained in Step 5.
   d. To access the Weighted Arithmetic Mean checkbox and inputs, click the arrow next to the Weighted Arithmetic Mean heading to expand the selection box as shown below (Figure 23) and in Figure 25.

Figure 23. Weighted arithmetic mean checkbox and input dialog box.



3. Select the total number of Suitability Indices to include in analysis pull-down menu
   a. For the pull-down menu, select the total number of parameter suitability index raster to include in the analysis (Figure 24).
   b. A minimum of 2 parameter suitability index rasters is required, with a maximum of 10 possible.

Figure 24. Pull-down menu selection for the total number of parameter suitability index rasters to include in the analysis.



4. Parameter suitability index rasters
   a. According to the total number of raster inputs selected in Step 3, the same number of input fields (First SI Raster, Second SI Raster, and Third SI Raster in Figure 27 below) will be enabled and required for input.

NOTE: The initial error icon will be displayed to denote required input. If the error icon remains after input, please click on the icon for additional information.

> WARNING: All input parameter suitability index raster files MUST have the same pixel resolution, spatial extent, and spatial reference to produce accurate calculations of habitat suitability. If requirements are not met, an error will be given and displayed next to all of the raster inputs.

b. Using the Folder icon, navigate to the directory where each parameter suitability index raster file is stored. The file may be in any raster format accepted by ArcGIS Pro (that is, geotiff, img, dat, ESRI GRID). The file should be a floating-point raster data type (for this exercise, `Hypothetical_NLCD_SI.tif`, `Hypothetical_DEM_SI.tif`, and `Hypothetical_SLOPE_SI.tif`).

c. The checkbox selections for Arithmetic Mean, Geometric Mean, and Minimum Limiting Factor only require input of parameter suitability index rasters; however, the Weighted Arithmetic Mean requires the parameter suitability index raster inputs as well as an integer weight values as explained in Step 5.

5. Output Final [STATISTICAL METHOD] Suitability Index Raster

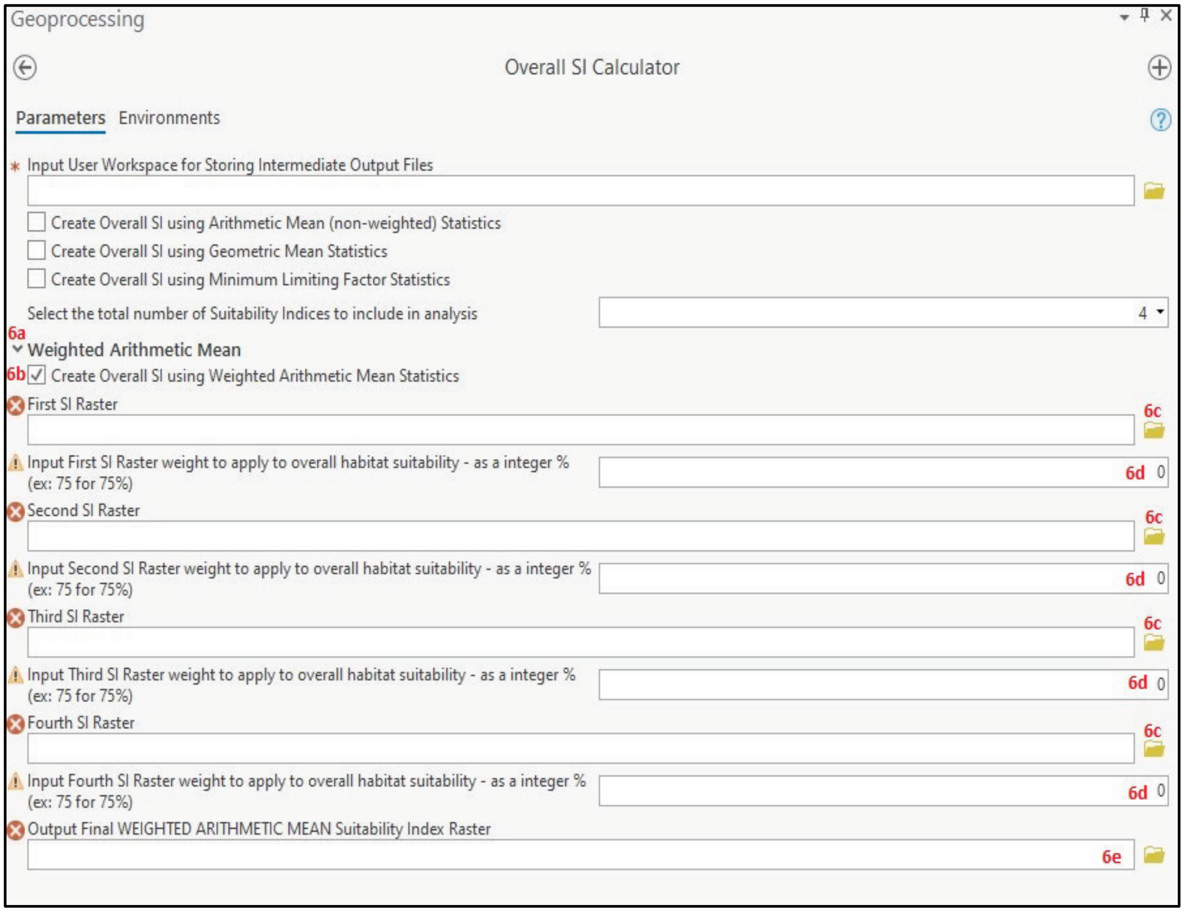
   a. Final output file options become active when the Arithmetic Mean, Geometric Mean, and Minimum Limiting Factor statistical option checkboxes are selected in Step 3.
   b. Using the Folder icon, navigate to the directory where the overall suitability index raster file will be stored. The file can be stored in any raster format accepted by ArcGIS Pro (that is, geotiff, img, dat, ESRI GRID). The file extension should be added to the filename, or an ESRI GRID will automatically be created as output. The output file will be a floating-point raster data type with a data range of 0.0–1.0.

6. Weighted Arithmetic Mean statistical option (Figure 25)

   a. The Weighted Arithmetic Mean statistical option located at the bottom of the dialog box is accessed by clicking the arrow to expand this statistical option.
   b. To calculate the overall suitability index using the Weighted Arithmetic Mean statistical option, click the checkbox. The total number of parameter suitability index raster inputs will be enabled per Step 3 selection.

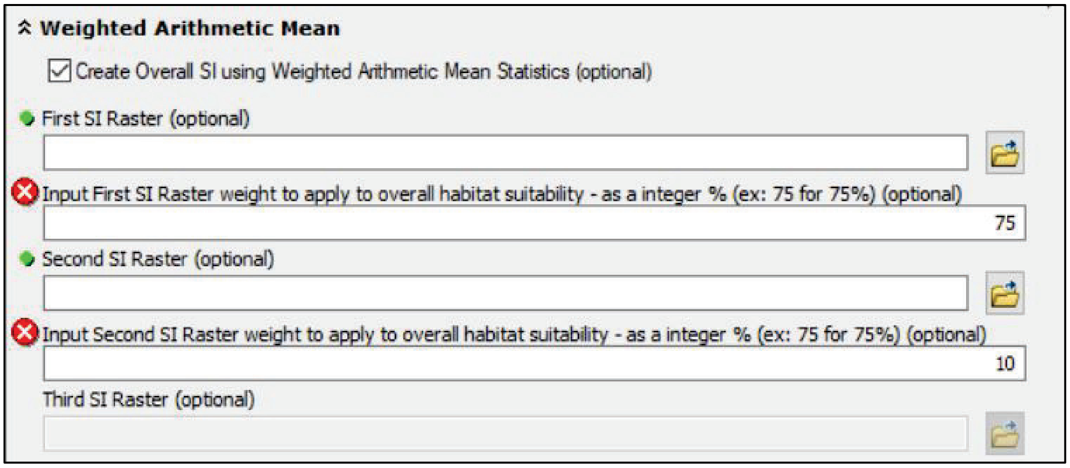
c. Click the Folder icon to browse and select the desired parameter suitability index raster.

Figure 25. OSIC WAM tool expansion displaying workflow numbers in *red* that correspond to the numbered steps below.



d. Enter a weighted integer value (0%–100%) to specify the amount of influence each parameter has on the overall habitat suitability. The total value of all parameter weights must equal 100% (Figure 26).

Figure 26. Example of the WAM weighted value error when all weights do not equal 100.

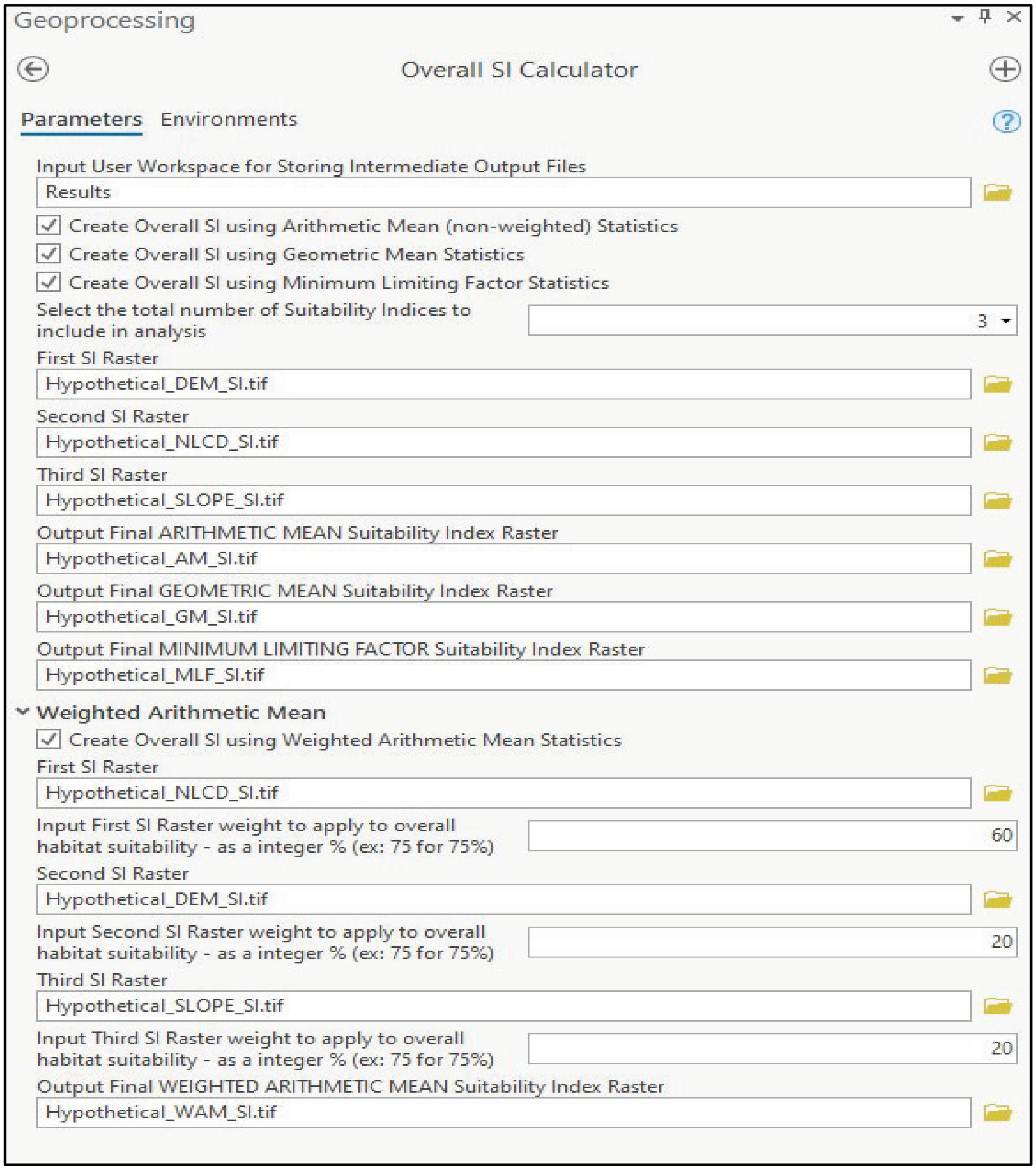


ERROR MESSAGE: If the total value of all parameter weights do not equal 100, an error will occur. All weight-value inputs will display this error until all weights have been assigned values and total 100%. The parameter weight is assigned zero (0%) by default and will show a warning symbol until a weight value is assigned.

e. To save the final WAM suitability index raster, click the Folder icon , navigate to output file folder location and enter an output file name. The OSIC tool dialog box will appear as shown in the figure below (Figure 27) with parameter input.

NOTE: If no file extension is provided, the tool will assume that the output will be in ESRI GRID format. Some commonly accepted raster file formats include: geotiff, img, dat.

Figure 27. The OSIC tool's dialog box for a hypothetical example.



7. To run the tool, click the Run button at the bottom right of the dialog box. Figure 28 displays a sample of the overall suitability index raster output.
8. Examples of the results are provided in the folder (`../SampleData/Results`) for AM (`Hypothetical_AM_SI.tif`) for WAM (`Hypothetical_WAM_SI.tif`), for GM (`Hypothetical_GM_SI.tif`), and for MLF (`Hypothetical_MLF_SI.tif`). The output is also shown in Figure 29.

Figure 28. Hypothetical overall suitability index raster output from the OSIC tool for Bayou Sara, Louisiana, HUC.

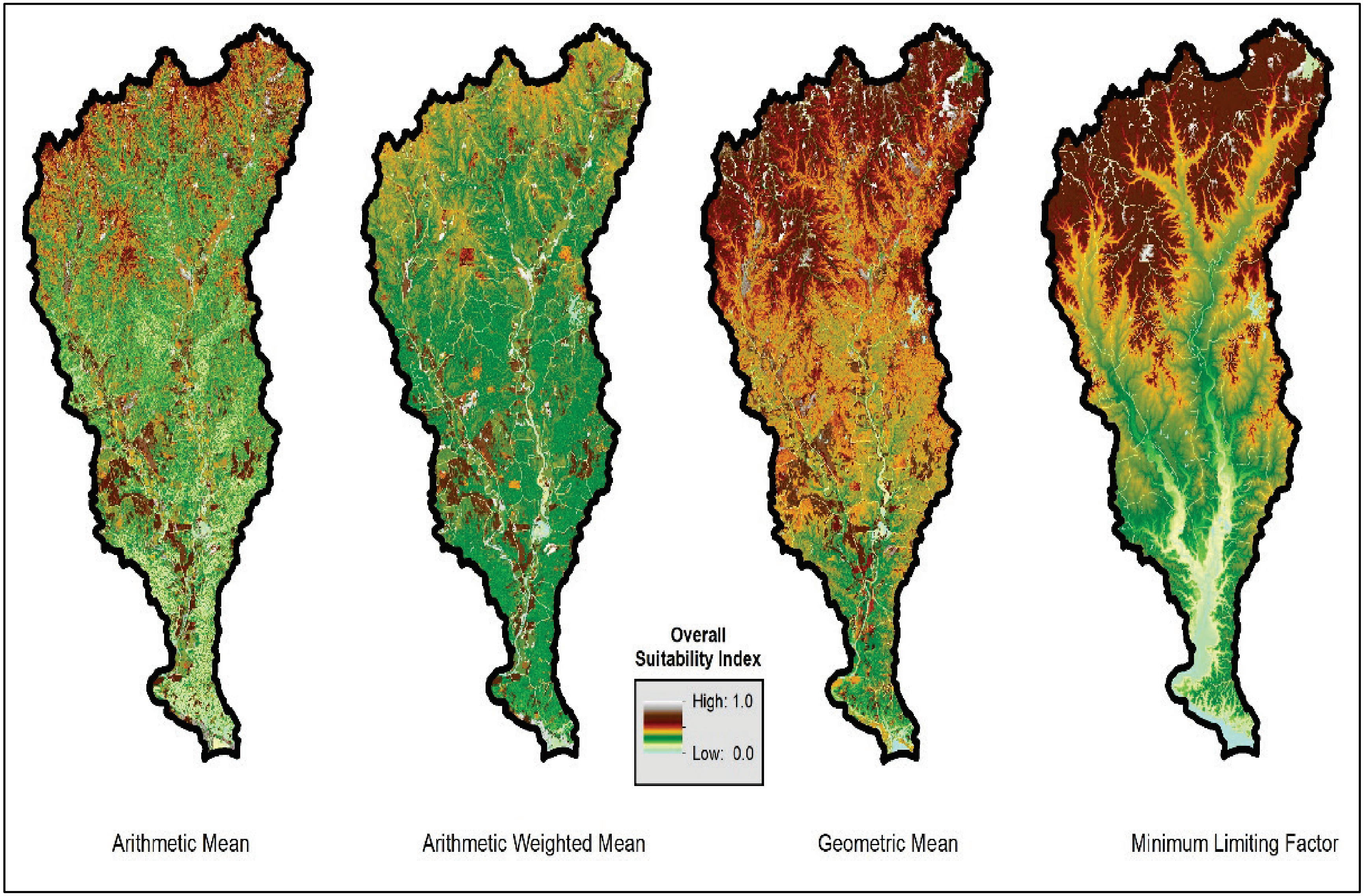


Figure 29. Hypothetical overall suitability index raster output WAM statistical option input description text file for Bayou Sara, Louisiana, HUC.

```
INPUT PARAMETERS FOR WEIGHTED ARITHMETIC MEAN FOR THE
FINAL SUITABILITY INDEX

..SampleData\HypotheticalExample\Results\Hypothetical_WAM_
SI.tif

The total number of Suitability Indices included in the
final weighted index is 3.

The FIRST parameter is:


.SampleData\HypotheticalExample\Results\Hypothetical_NLCD_
SI.tif with assigned WEIGHT 60%.

The SECOND parameter is:

..SampleData\HypotheticalExample\Results\Hypothetical_DEM_
SI.tif with assigned WEIGHT 20%.

The THIRD parameter is:

..SampleData\HypotheticalExample\Results\Hypothetical_SLOP
E_SI.tif with assigned WEIGHT 20%.

The FOURTH parameter is None with assigned WEIGHT 0%.

The FIFTH parameter is None with assigned WEIGHT 0%.

The SIXTH parameter is None with assigned WEIGHT 0%.

The SEVENTH parameter is None with assigned WEIGHT 0%.
```

9. Included in the output file creation is a descriptive text file containing the location of all input parameters, associated weights, and final output

filename and location. The name of this text file includes the output filename with a .txt extension. Examples of the results are provided in the folder `../SampleData/Results` for AM (`Hypothetical_AM_SI.txt`) for WAM (`Hypothetical_WAM_SI.txt`), for GM (`Hypothetical_GM_SI.txt`), and for MLF (`Hypothetical_MLF_SI.txt`). The sample output for the WAM is shown in Figure 29.

6 Conclusion

In summary, the GSI toolbox allows users to rapidly develop and apply integrated ecological models across large spatial domains. It uses thematic- and continuous-raster data sets to combine multiple ecosystem indices into a single integrated raster layer representing habitat suitability as an index range of 0.0 to 1.0, where zero (0) is nonsuitable and one (1) is most suitable. This report provides detailed guidance on the installation and implementation of the GSI toolbox's capabilities through step-by-step instructions using hypothetical examples. The toolbox output can be used in environmental studies such as ecosystem-restoration planning, environmental-impact assessments, and invasive-species assessments where habitat quality and quantity are desired. Potential future expansion of the toolbox could include the support for vector-based parameter data and sensitivity tests for evaluating individual model parameters in relation to the overall model suitability. For more information on this toolbox as well as other ecological models developed by ERDC, please refer to the Ecosystem Management and Restoration Research Program, or EMRRP, Models and Applications website: https://emrrp.el.erdc.dren.mil/models.html.

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Appendix: Figure 1 Text Outline

A plain-text version of Figure 1 is available below:

1. Geospatial Suitability Index
    a. Suitability Index Calculator
        i. Input Parameters
            1. LOI Polygon
            2. Parameter Raster File
            3. Suitability Table (CSV)
        ii. Output
            1. Parameter SI Raster
            2. Each tool run creates one parameter SI raster
    b. Overall Suitability Index
        i. Input Parameters
            1. Multiple Parameter SI Rasters (at least two)
            2. Parameter Weights
            3. Statistical Options
                a. Arithmetic Mean (AM)
                b. Geometric Mean (GM)
                c. Minimum Limiting Factor (MLF)
                d. Weighted Arithmetic Mean (WAM)
        ii. Output
            1. Overall SI Raster

Abbreviations

AM	Arithmetic mean
CSV	Comma separated values
DEM	Digital elevation model
ERDC	Engineer Research and Development Center
ESRI	Environmental Systems Research Institute
GIS	Geographic information systems
GM	Geometric mean
GSI	Geospatial suitability index
his	Habitat suitability index
HUC	Hydrologic unit code
LOI	Location of interest
MLF	Minimum limiting factor
OSIC	Overall suitability index calculator
SIC	Suitability index calculator
TAM	Toolkit for interActive Modeling
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WAM	Weighted arithmetic mean

REPORT DOCUMENTATION PAGE

OMB No. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
08/01/2022	Final	FY16–FY19

4. TITLE AND SUBTITLE
Geospatial Suitability Indices (GSI) Toolbox:
User's Guide

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT

6. AUTHOR(S)
Christina Saltus, S. Kyle McKay, and Todd Swannack

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Engineer Research and Development Center (ERDC)
Environmental Laboratory (EL)
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
ERDC/EL SR-22-4

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Engineer Research and Development Center (ERDC)
Environmental Laboratory (EL)
Ecosystem Management and Restoration Research Program (EMRRP)
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
Civil Direct—Funding Account Code U4357261, AMSCO Code 031342

14. ABSTRACT

Habitat suitability models have been widely adopted in ecosystem management and restoration to assess environmental impacts and benefits according to the quantity and quality of a given habitat. Many spatially distributed ecological processes require application of suitability models within a geographic information system (GIS). This technical report presents a geospatial toolbox for assessing habitat suitability. The geospatial suitability indices (GSI) toolbox was developed in ArcGIS Pro 2.7 using the Python 3.7 programming language and is available for use on the local desktop in the Windows 10 environment. Two main tools comprise the GSI toolbox. First, the suitability index (SIC) calculator tool uses thematic or continuous geospatial raster layers to calculate parameter suitability indices using user-specified habitat relationships. Second, the overall suitability index calculator (OSIC) combines multiple parameter suitability indices into one overarching index using one or more options, including arithmetic mean, weighted arithmetic mean, geometric mean, and minimum limiting factor. The result is a raster layer representing habitat suitability values from 0.0–1.0, where zero (0) is unsuitable habitat and one (1) is ideal suitability. This report documents the model purpose and development and provides a user's guide for the GSI toolbox.

15. SUBJECT TERMS
Environmental management; Ecology--Mathematical models; Habitat suitability index models; Geospatial data; Geographic information systems

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Christina Saltus
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (include area code)
Unclassified	Unclassified	Unclassified	SAR	65	(601) 634-3958