Guidelines for Using the Climate Change Vulnerability Index

2024 Release 4.0

Recommended citation

Lyons, Marta P., Stevenson, John R., Thurman, Lindsey L., and Young, Bruce E. (2024) Guidelines for Using the NatureServe Climate Change Vulnerability Index, Release 4.0. Arlington, VA: NatureServe.

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Acknowledgments

We would like to thank the many technical advisors who provided valuable input into the development of this latest release of the CCVI. We would specifically like to thank:

Sarah Endicott, Environment and Climate Change Canada,
Christopher Hoving, Michigan Department of Natural Resources,
Bryce Maxell, Program Coordinator, Montana Natural Heritage Program,
Ilona Naujokaitis-Lewis, Environment and Climate Change Canada,
Dianne Robinson, Texas A&M Natural Resource Institute,
Sienna Wessel, Washington Natural Heritage Program.

This research was funded by the U.S. Geological Survey's regional Climate Adaptation Science Centers in the Northwest, Southwest, North Central, South Central, Midwest, Southeast and Northeast regions. This research was also supported in part by an appointment to the U.S. Geological Survey Research Participation Program administered by the Oak Ridge Institute for Science and Education through an interagency agreement between the U.S. Department of Energy and the U.S. Department of the Interior. The Oak Ridge Institute for Science and Education is managed by Oak Ridge Associated Universities under the U.S. Department of Energy.

Funding G23AC00143-00

Photo credit

Columbia torrent salamander (*Rhyacotriton kezeri*) by Christopher Cousins (public domain).

Contents

Quick Start Guide 5

Introduction 7

Module A. Exposure to Local Climate Change 8

Module B: Exposure to Sea Level Rise 10

Module C: Distribution 11

C1: Extent of Occurrence 11

C2: Area of Occupancy 12

C3: Habitat Specialization 12

C4: Commensalism with Humans 13

C5: Geographic Rarity 13

Module D: Movement 14

D1: Dispersal Syndrome 14

D2: Dispersal Distance 15

D3: Dispersal Phase 15

D4: Site Fidelity 16

D5: Migration Frequency 16

D6: Migration Demography 17

D7: Migration Timing 17

D8: Migration Distance 17

Module E: Evolutionary Potential 18

E1: Genetic Diversity 18

E2: Population Size 19

E3: Hybridization Potential 19

Module F: Ecological Role 20

F1: Enemies 20

F2: Diet Breadth 21

F3: Diversity of Obligate Species 21

Module G: Abiotic Niche 22

G1: Seasonal Phenology 22

G2: Climatic Niche Breadth 23

G3: Physiological Tolerances 24

G4: Behavioral Regulation of Physiology 25

G5: Disturbance Tolerances 26
Module H: Life History 27
H1: Reproductive Phenology 27
H2: Reproductive Mode 28
H3: Mating System 28
H4: Fecundity 29
H5: Parity 29
H6: Sex Ratio 30
H7: Sex Determination 31
H8: Parental Investment 32
Module I: Demography 33
I1: Life Span 33
I2: Generation Time 33
I3: Age of Sexual Maturity 34
I4: Age Structure 34
I5: Recruitment 35
Module J: Threat Multipliers (other extrinsic factors that affect climate change vulnerability) 36
J1: Topographic Barriers to Movement 36
J2: Anthropogenic Barriers to Movement 38
J3: Land-use Change 39
J4: Other anthropogenic threats 40
J5: Other Biological Threats 41
Module K: Documented or Modeled Response to Climate Change 42
K1: Documented Response to Recent Climate Change 42
K2: Modeled Future (e.g., mid-century) Change in Range or Population Size 43
K3: Overlap of Modeled Future (e.g., mid-century) Range with Current Range 44
K4: Occurrence of Protected Areas in Modeled Future (e.g., mid-century) Distribution 44
References 45
Appendix A: Algorithm 47
Appendix B: Sea Level Rise 48

Quick Start Guide

1. The CCVI online and Excel Workbook versions of the release 4.0 are available at https://www.natureserve.org/ccvi-species.

The following steps apply to both the Online and Excel Workbook versions, unless otherwise indicated:

2. **Assessor/Assessed Information**
    a. Complete the information requested; required fields are indicated in red with an asterisk.
    b. Please note the following fields are required and leaving them blank will prevent you from moving on to subsequent modules in the online version or from obtaining CCVI results in either version:
        i. Geographic Area Assessed
        ii. Species Scientific Name
        iii. Kingdom
        iv. Major Taxonomic Group
3. **Module A:** Exposure to Local Climate Change
    a. The CCVI online module executes a geoprocess that calculates the projected exposure to climate change within the geographic area assessed by mid-century. Two climate change scenarios are considered: RCP 4.5 and RCP 8.5.
        i. You may either (1) upload a shapefile, (2) draw the range of your species within the assessment area directly on the map, or (3) select a state from the drop-down menu.
    b. The CCVI Excel Workbook offers a drop-down menu with state-wide exposure values that, once selected, will be used in the algorithm. Alternatively, you may compute exposure for a specific area using the online version and enter those results in the Option 2 fields of the Excel workbook.
    c. Completing this module is required.
4. **Module B:** Exposure to Sea Level Rise
    a. This module accounts for exposure to sea level rise. If your species may be affected by sea level rise, follow the directions in Appendix B for using the NOAA website to calculate exposure and enter the result here. If your species is not affected by sea level rise, select Neutral for this factor.
    b. Completing this module is required.
5. **Modules C through I:** Adaptive Capacity
    a. The modules address adaptive capacity to climate change
    b. Score each factor as to the degree each influences the adaptive capacity of the focal species or population within the geographic area assessed, if possible. Scoring options vary by factor; grayed responses are not available for scoring.
    c. Completing at least one factor in 6 of the 7 modules is required.
6. **Module J:** Threat Multipliers
    a. The factors in this module address additional threats that may exacerbate climate change vulnerability.
    b. Completing at least 3 of the 5 factors is required.
7. **Module K:** Documented or Modeled Response to Climate Change
    a. Score factors in this section if there is information available from the literature about how the species has already responded to climate change, for example, if the results of a range-shift model are available.

b. This module is optional.

8. **Summary Reports**
   a. In the CCVI online version, the Module Summary tab displays the percentage of the factors in each module that were scored. The Scoring tab presents qualitative results for Climate Exposure (Module A), Adaptive Capacity (Modules C-I), Threat Multipliers (Module J), and Overall CCVI category. Use the Previous Tab and Next Tab buttons to navigate among the modules.

   b. In the CCVI Excel Workbook, the Results Report tab displays summary results for your assessment. The Results Table tab displays your Form tab responses in table form *after you click* the 'Copy Data to Results Table' button at the bottom of the Form tab.

Introduction

Motivated by the need for a means to rapidly assess the vulnerability of species to climate change, NatureServe developed a Climate Change Vulnerability Index (CCVI) in the early 2010s. The CCVI has gone through several revisions, including the widely used version 3.0 in 2016. This latest release (4.0), represents the first revision since 2016 and is now available as a web-based online version and as a downloadable Excel Workbook version

The CCVI uses a scoring system that integrates a species' exposure to projected climate change within an assessment area, including consideration of sea level rise where applicable, and three sets of factors associated with adaptive capacity, each supported by published studies: 1) species-specific adaptive capacity factors; 2) threat multipliers, such as barriers to dispersal and anthropogenic threats; and 3) documented and modeled responses to climate change.

Assessing species with the CCVI facilitates grouping unrelated taxa by their relative risk to climate change, as well as identifying patterns of climate stressors that affect multiple taxa. A primary goal for the CCVI 4.0 is to continue providing input for planning documents, such as State Wildlife Action Plans, to allow consideration of climate change impacts together with other stressors. Further, we hope that this tool will help resource managers develop and prioritize strategies for climate adaptation that increase the resilience and adaptive potential of species to climate change. This document provides instructions along with a description of the underlying algorithm.

The CCVI 4.0 incorporates Multivariate Adaptive Constructed Analogs (MACA) exposure data derived from projected mid-century departures in temperature and climate moisture deficit using an ensemble of 20 global climate models (GCMs) of the Coupled Model Inter-Comparison Project 5 (CMIP5) climate data. Both Representative Concentration Pathway (RCP) 4.5 (intermediate) and RCP 8.5 (worst-case) scenarios are provided for comparison. The CCVI 4.0 also uses a framework for measuring adaptive capacity described by Thurman et al. (2020). Modules C – I now replace the Sensitivity and Adaptive Capacity section of previous CCVI releases. As an online tool, this release allows users to save and return to assessments as well as "publish" and share completed assessments that other users can view to inform their own assessments.

Additional resources

- MACA climate data: https://climate.northwestknowledge.net/MACA/
- Original description of CCVI (Young et al. 2012): https://www.natureserve.org/sites/default/files/publications/files/ns161.05-young-et-al.pdf
- Description of initial revisions (Young et al. 2015): https://wildlife.onlinelibrary.wiley.com/doi/pdfdirect/10.1002/wsb.478
- Description of adaptive capacity framework (Thurman et al. 2020): https://esajournals.onlinelibrary.wiley.com/doi/pdfdirect/10.1002/fee.2253

Module A. Exposure to Local Climate Change

Exposure is calculated as the rescaled, combined change in temperature and climatic water deficit across the geographic area assessed for the taxon of interest. The multi-model mean projections for 2040-2069 were compared to a historical baseline of 1971-2000 for 20 downscaled climate models using MACAv2-METDATA (Abatzoglou & Brown 2012) accessed through the web-based tool Climate Toolbox (Hegewisch et al. 2018).

- Temperature: annual average of the mean of daily mean temperatures, computed as the mean of daily high and low temperatures, computed over the time period.
- Climatic Water Deficit: Sum of the annual difference between potential evapotranspiration and actual evapotranspiration. It is the evaporative demand that is not met by available water.

Both variables were individually rescaled to a range between 0 (no change from historical baseline) and 1 (maximum change under high emissions [RCP8.5] scenario) and then the two variables were averaged for a final exposure value between 0 and 1. We chose to use moderate (RCP4.5) and high (RCP8.5) emissions scenarios from the Intergovernmental Panel on Climate Change Coupled Model Intercomparison Project Phase 5 (CMIP5). Using two emissions scenarios generates two exposure values and two final vulnerability scores that reflect uncertainty in future societal actions to confront climate change.

<u>Calculating Exposure with CCVI online tool</u>:

1. Define spatial extent(s) to reflect the distribution of the taxon being assessed within the geographical area of interest:
   - Option 1 (Shapefile): You may upload a shapefile by clicking on "UPLOAD SHAPEFILE" in blue text. The shapefile must be stored in a compressed (.zip) folder consisting of a collection of files with a common filename prefix. The three mandatory files have filename extensions .shp, .shx, and .dbf. Note that the CCVI exposure tool cannot compute exposure for shapefiles that are 1) point-based, 2) exceed 5 MB or 3) contain too many vertices. If your file has too many vertices and the site freezes while calculating exposure, or the file size is too large to load (> 5 MB), you should consider simplifying the number of vertices (and thereby reducing the file size) by using one of options noted in the Tools section, below.
   - Option 2 (Draw an extent): You may use the "Draw polygon" icon to draw single or multiple polygons to represent the distribution of the taxon. You may then select your drawn polygon(s) using the "Select feature," "Select by Rectangle," or "Select by Lasso" options. You may edit or move the polygon by clicking on the shape and toggling between the orange lines and point vertices with either the left or right mouse buttons. Once the point vertices are shown you may select and move and/or edit the shape.
   - Option 3 (select a state): Select the state where the assessment takes place from the drop-down menu.
2. Calculate: Once you have provided the spatial extent(s) for the species of interest using one of the three options, click the blue "CALCULATE" icon and exposure values will be calculated for the area(s) you have identified with the polygon(s).
3. If you modify the polygon(s) on the map after clicking CALCULATE, warning triangles will appear next to the exposure values until you click CALCULATE to use the exposure information for the new area in the CCVI algorithm.

Calculating Exposure for Excel version:

The Excel version offers two alternatives for entering exposure data:

- Option 1: Use state boundaries to approximate the distribution of your taxon. Use the drop-down menu for Option 1 in the Module A section and select your state of interest.
- Option 2: Enter exposure values manually in Option 2 in the Module A section. You can obtain these values in one of three ways:
    - Use Module A of the CCVI online tool and follow the instructions above.
    - Download the exposure raster dataset from the CCVI-2024 webpage (https://www.natureserve.org/ccvi-species) and overlay a polygon representing the distribution of the taxon being assessed to calculate the average exposure.
    - Use any other climate exposure data that has been rescaled from 0-1, overlay a distribution polygon, and calculate average exposure. Note that the CCVI has been tuned to produce best results for the MACA data provided and that use of alternative climate data may result in skewed outcomes.

Additional tools available:

- Shapefile repositories: USGS hosts a range of spatial boundary datasets that you may find useful including administrative boundaries (e.g., state) and watersheds at https://apps.nationalmap.gov/downloader/. Note that you must make selections for the types of datasets you are looking for then use the blue “Search Products” button at the top of the page. Some of these files are large and may require the ability to alter downloaded shapefiles to meet the maximum 5MB file size limit for the CCVI online tool.
- Simplifying shapefile vertices can speed up exposure calculations and tools to do this exist in ArcGIS Pro (Simplify Polygon), QGIS (Simplify), and R software (using *st_simplify* function in the *sf* package).

Module B: Exposure to Sea Level Rise

This factor only applies in cases where all or a portion of the species' range within the assessment area may be subject to the effects of sea level rise and the consequent influence of storm surges and intrusion of salt water. The negative impact of sea level rise on habitats for most affected species is expected to be high.

Tools: To visualize potential sea level rise in coastal areas of the U.S., see Appendix B for instructions on estimating inundation for your area(s) of interest: https://coast.noaa.gov/slr/.

Category	Category definition
Greatly Increases Vulnerability:	>90% of range occurs in area subject to sea level rise (on low-lying island(s) or in coastal zone).
Increases Vulnerability:	50-90% of range occurs in area subject to sea level rise (on low-lying island(s) or in coastal zone).
Somewhat Increases Vulnerability:	10-49% of range occurs in area subject to sea level rise (on low-lying island(s) or in coastal zone).
Neutral:	<10% of range occur in area subject to sea level rise (on low-lying island(s) or in coastal zone). Includes inland areas not subject to sea level rise. Also, species that occur in an intertidal habitat that is expected to increase in extent with a rising sea level.

Modules C-I: Adaptive Capacity

Modules C – I include 37 species- or population-level factors from Thurman et al (2020) to assess adaptive capacity (AC). Two new factors, “Enemies” and “Disturbance Tolerances”, have been added. Factors are grouped into seven complexes, corresponding to modules C through I. Each module provides all factor definitions, relevant scale(s) of assessment, and evaluation criteria. For more background information, see Thurman et al. (2020).

Evaluate these factors for the specific taxonomic scale and geographical area under consideration, if possible.

Module C: Distribution

C1: Extent of Occurrence

The area contained within the shortest continuous boundary that can be drawn to encompass all known, inferred, or projected sites of present occurrence of a taxon, excluding cases of vagrancy (IUCN 2012). In the case of migratory species, Extent of Occurrence should be based on the minimum of breeding or non-breeding areas, but not both, because the bulk of the population is found in only one of these areas at any given time.

Category	**Category definition**
Low adaptive capacity:	<100 km2
Moderately low adaptive capacity:	100–5000 km2
Moderately high adaptive capacity:	5000–20,000 km2
High adaptive capacity:	>20,000 km2

C2: Area of Occupancy

The area within a species' Extent of Occurrence, excluding cases of vagrancy (IUCN 2012). Area of Occupancy is a scaled metric that represents the area of suitable habitat currently occupied and is a measure of "insurance effect," wherein taxa that occur within many patches or large patches across a landscape are insured against risks from spatially explicit threats. Area of Occupancy reflects the fact that a taxon will not usually occur throughout the area of its Extent of Occurrence, which may contain unsuitable or unoccupied habitats. In some cases, the Area of Occupancy is the smallest area essential at any stage to the survival of existing populations of a species. The size of the Area of Occupancy will be a function of the scale at which it is measured, and should be at a scale appropriate to relevant biological aspects of the taxon, the nature of threats, and available data.

Category	Category definition
Low adaptive capacity:	<10 km2
Moderately low adaptive capacity:	10–500 km2
Moderately high adaptive capacity:	500–2,000 km2
High adaptive capacity:	>2,000 km2

C3: Habitat Specialization

Also referred to as habitat specificity. Habitat Specialization evaluates the use of a relatively restricted subset of habitats, with narrow or well-defined physical or biotic characteristics, for the purposes of foraging, breeding, and other important life-cycle processes, including the reliance on particular habitats through which a species can move.

Category	Category definition
Low adaptive capacity:	Highly dependent on a particular habitat (more or less endemic to, or contains >85% of occurrences)
Moderate adaptive capacity:	Moderately dependent on a particular, uncommon, habitat; (1) an indicator of, but not an endemic to that habitat (contains 65–85% of occurrences); OR (2) more or less restricted to a habitat that is uncommon within the species' range, but is not one of the dominant types within that range.
High adaptive capacity:	Having a clear preference for a particular habitat (contains >85% of occurrences), but the habitat is among the dominant types within the species' range; OR somewhat flexible in habitat utilization; OR described as a habitat generalist and/or occurrence has been documented on widely varied habitat types

C4: Commensalism with Humans

Degree of tolerance of human interactions and infrastructure.

Category	Category definition
Low adaptive capacity:	Intolerant of human influences and/or human-dominated landscapes
Moderate adaptive capacity:	Moderately tolerant of human influences, utilization of semi-natural landscapes (e.g., agricultural fields, suburban parks)
High adaptive capacity:	Highly tolerant of human influences, wide utilization of human-dominated landscapes

C5: Geographic Rarity

Sensu Rabinowitz (1981); takes into consideration that some species may be broadly distributed in their spatial extent but simultaneously exhibit patchiness in their occurrence, or low local abundance.

Category	Category definition
Low adaptive capacity:	Geographically restricted with isolated populations
Moderately low adaptive capacity:	Geographically restricted with highly connected populations (e.g., endemic species)
Moderately high adaptive capacity:	Broadly distributed with sparse or isolated populations
High adaptive capacity:	Broadly distributed with highly connected populations (i.e., common)

Module D: Movement

A note on dispersal vs. migration: Dispersal pertains to one-way (unidirectional) movement and involves the movement of an individual or multiple individuals away from the population in which they were born to another location (i.e., natal dispersal) where they will settle and reproduce (i.e., movement that contributes to gene flow). Migration includes seasonal (bi-directional) movement and is a round-trip journey for individuals to take advantage of more favorable conditions with respect to food availability, safety from predation, mating opportunities, or other environmental factors.

D1: Dispersal Syndrome

The degree of flexibility in either the timing or mechanism of dispersal. For mobile organisms, dispersal can either be obligate (dispersal events are fixed within a specific life stage) or facultative (individuals can "choose" if and when to disperse). For sessile organisms, dispersal syndrome refers to the morphological characteristics of seeds or propagules that are correlated with particular dispersal agents.

Option 1: Mobile species

Category	Category definition
Low adaptive capacity:	Obligate (fixed timing, or dependence on a specific cue)
Moderate adaptive capacity:	NA
High adaptive capacity:	Facultative (flexible timing, or no cue dependence)

Option 2: Sessile species

Category	Category definition
Low adaptive capacity:	Dependence on invertebrate or vertebrate vector(s) with low mobility
Moderately low adaptive capacity:	Dependence on invertebrate or vertebrate vector(s) with high mobility
Moderately high adaptive capacity	Localized (i.e., gravity or explosive dehiscence)
High adaptive capacity:	Wind or water currents

D2: Dispersal Distance

The distance an individual or propagule can move from an existing population's location, or a population's average location.

Category	Category definition
Low adaptive capacity:	Species is characterized by severely restricted dispersal or movement capability (<10 m per dispersal event)
Moderately low adaptive capacity:	Species is characterized by highly restricted dispersal or movement capability; species rarely disperses through unsuitable habitat more than about 10–100 m per dispersal event; OR dispersal beyond a very limited distance (or outside a small, isolated patch of suitable habitat) periodically or irregularly occurs, but is dependent on highly fortuitous or rare events; OR species has substantial movement capability but exhibits a very high degree of site fidelity
Moderately high adaptive capacity	Species is characterized by limited (or moderate), but not highly or severely restricted, dispersal or movement capability; a large percentage (at least 50%) of propagules or individuals disperse approximately 100–1000 m per dispersal event (rarely farther); OR species has substantial movement capability, but exhibits a moderate to high degree of site fidelity and has very limited existing or potential habitat within the assessment area
High adaptive capacity:	Species is characterized by good to excellent dispersal or movement capability; species has propagules or dispersing individuals that commonly move more than 1 km from natal or source areas; OR species tends to occupy all or most areas of suitable habitat, or readily or predictably moves more than 1 km to colonize newly available habitat

D3: Dispersal Phase

The phase or life-stage in which individuals or propagules disperse.

Category	Category definition
Low adaptive capacity:	Short period or discrete phase (e.g., life stage)
Moderate adaptive capacity:	NA
High adaptive capacity:	Long period or throughout life

D4: Site Fidelity

Natal site fidelity (the propensity to be a "stayer" within the population) allows for locally adapted life history traits that increase reproductive success and fitness. Alternatively, "straying" during dispersal events promotes the colonization of new habitats, increases opportunities for genetic mixing among populations, and can buffer populations from variation in habitat quality.

Category	Category definition
Low adaptive capacity:	High site fidelity (higher proportion of "stayers")
Moderate adaptive capacity:	Moderate site fidelity (roughly equal proportion of "stayers" and "strayers")
High adaptive capacity:	Low site fidelity (higher proportion of "strayers")

Factors D5 – D8 are behaviors related to migration (note, if the species being assessed is non-migratory, these factors should be scored as "NA."). These factors reflect the degree of flexibility in migratory events and dependence on environmental cues (and degree of risk associated with the cues at departure being independent of conditions at destination). With respect to migration phenology, migration can be obligate (individuals must migrate given a specific cue), or facultative (individuals can "choose" to migrate or not) and a population can exhibit complete, partial (some individuals reside on the breeding site year-round, while others migrate), or differential migration (individuals from a population migrate different distances or to different locations).

D5: Migration Frequency

The frequency in which individuals of a population migrate within their lifetime.

Category	Category definition
Low adaptive capacity:	Once during lifetime
Moderate adaptive capacity:	NA
High adaptive capacity:	Throughout lifetime (annually or seasonally)

D6: Migration Demography

The proportion of individuals in a population that migrate during a migratory event.

Category	Category definition
Low adaptive capacity:	Complete (most or all individuals within a population migrate)
Moderate adaptive capacity:	Partial (some individuals reside on breeding/natal grounds year-round, while others migrate)
High adaptive capacity:	Differential (individuals migrate different distances or to different locations)

D7: Migration Timing

The timing of migration and dependence on environmental cues.

Category	Category definition
Low adaptive capacity:	Obligate (fixed timing or reliance on environmental cue or resource)
Moderate adaptive capacity:	NA
High adaptive capacity:	Facultative (flexible timing and independent of environmental cue or resource)

D8: Migration Distance

The total, geographic distance spanned during a migratory event. Long-distance migrants have shown steeper population declines than their resident and short-distance migratory counterparts. Ecological conditions at stopover sites, along with weather conditions, affect the survival, schedules, and reproductive success of migrants. Long-distance migrants are therefore at increased risk of exposure to spatially heterogeneous threats.

Category	Category definition
Low adaptive capacity:	Long-distance migration (e.g., crosses geopolitical, large-landscape, or ecotypic boundaries)
Moderate adaptive capacity:	Variation in distances or destinations within a population/species (differential migration)
High adaptive capacity:	Local migration

Module E: Evolutionary Potential

E1: Genetic Diversity

The diversity of genotypes (or genetic variability) within a species. Genetic diversity can be subdivided into adaptive vs neutral genetic diversity. Neutral genetic diversity confers no direct effect on fitness, or the adaptive potential of a population, but it can inform processes such as genetic drift, gene flow, dispersal, and migration (i.e., functional connectivity). Adaptive genetic diversity is the genetic variation under natural selection; it informs a population's evolutionary adaptive potential and is assessed in quantitative genetic experiments.

Category	**Category definition**
Low adaptive capacity:	Low, within-population genetic variability; OR genetic variation reported as "very low" compared to findings using similar techniques on related taxa (i.e., lack of genetic variation has been identified as a conservation issue for the species; OR evidence that total population was reduced to ≤250 mature individuals, one occurrence, and/or that occupied area was reduced by >70% at some point in the past 500 years
Moderate adaptive capacity:	Moderate, within-population genetic variability; OR genetic variation reported as "low" compared to findings using similar techniques on related taxa; OR evidence that total population was reduced to 251–1000 mature individuals, to less than ten occurrences, and/or that occupied area was reduced by 30–70% at some point in the past 500 years
High adaptive capacity:	High, within-population genetic variability; OR genetic variation reported as "average" or "high" compared to findings using similar techniques on related taxa; OR No evidence that total population was reduced to ≤1000 mature individuals and/or that occupied area was reduced by >30% at some point in the past 500 years

E2: Population Size

The number of individuals in a population or metapopulation that co-occur in a particular geographic area and are capable of interbreeding, including those who contribute offspring to the next generation (i.e., all reproducing individuals in that population) and non-reproducing individuals (adapted from IUCN Red List thresholds, IUCN Standards and Petitions Subcommittee 2019); Population size should be evaluated with consideration of genetic diversity and gene flow, wherein a population contains individuals that are more genetically related than individuals of other populations from which they are physically and/or genetically isolated.

Category	**Category definition**
Low adaptive capacity:	<250 mature individuals (low local abundance), or estimated population decline by ≥25% within 3 years or one generation, whichever is longer
Moderately low adaptive capacity:	<2500 mature individuals, or estimated population decline by ≥20% within 5 years or two generations, whichever is longer
Moderately high adaptive capacity:	<10,000 mature individuals, or estimated population decline by ≥10% within 10 years or three generations, whichever is longer
High adaptive capacity:	>10,000 mature individuals (high local abundance), with high probability of long-term persistence

E3: Hybridization Potential

Existence of closely related species, subspecies, or allopatric populations for interbreeding, with much consideration of fitness consequences such as outbreeding depression.

Category	**Category definition**
Low adaptive capacity:	Hybridization does not occur OR hybridization occurs but offspring are not viable, or have lower fitness
Moderate adaptive capacity:	Hybridization probably occurs (fitness consequences unknown)
High adaptive capacity:	Hybridization occurs; offspring are viable (minimal to no fitness consequences)

Module F: Ecological Role

F1: Enemies

Consideration of biotic interactions is essential to accurately predicting species' responses to climate change as some species may be favored while others become disadvantaged. Climate change can disrupt food webs by altering the distribution or abundance of species that act as key resources, competitors, or predators in the system, or by shifting phenology and synchronies of interacting organisms (e.g., host-pathogen dynamics), ultimately causing important changes in the nature of relationships among species. Climate change can also be a driver of species introductions and range shifts, resulting in new and novel interactions.

Category	**Category definition**
Low adaptive capacity:	Strongly affected by a native or non-native species that is likely to be favored by climate change; OR climate change is likely to substantially increase the prevalence of the natural enemy (or enemies); OR significant disruptions to trophic or non-trophic interactions, with consequences for species' fitness or access to critical resources (e.g., through altered predator-prey interactions, competition, or disease dynamics)
Moderate adaptive capacity:	Moderately affected by a native or non-native species that is likely to be favored by climate change; OR climate change is likely to only marginally increase the prevalence of the natural enemy (or enemies); OR disruptions to trophic or non-trophic interactions likely to have minimal consequences for species' fitness or access to critical resources (e.g., through altered predator-prey interactions, competition, or disease dynamics)
High adaptive capacity:	Little or no response to a native or non-native species that is likely to be favored by climate change; OR climate change is likely to reduce or have no impact on the prevalence of the natural enemy (or enemies); OR no significant disruptions to trophic or non-trophic interactions, with no significant consequences for species' fitness or access to critical resources (e.g., through altered predator-prey interactions, competition, or disease dynamics)

F2: Diet Breadth

Also referred to as diet versatility or flexibility; ability to utilize a range of food resources, or to be flexible in prey preference. This factor is not relevant to plants and other primary producers.

Category	Category definition
Low adaptive capacity:	Completely or almost completely (>90%) dependent on one food item (species) during any part of the year; equivalent alternatives to this single-species food resource are not readily available
Moderate adaptive capacity:	Completely or almost completely (>90%) dependent during any part of the year on either (1) a few species from a restricted taxonomic group, or (2) a narrow guild the members of which are thought to respond similarly to climate change
High adaptive capacity:	Diet flexible; during any season species readily switches among multiple food resources according to availability; OR not strongly dependent on one or a few species; OR omnivorous, with diet including numerous species of both plants and animals

F3: Diversity of Obligate Species

Also referred to as interspecific dependencies; the number of obligate species interactions, including mutualists, pollinators, dispersers, etc., that a focal species relies on to complete some aspect of its life cycle not pertaining to food resources.

Category	Category definition
Low adaptive capacity:	Obligated to one or few species
Moderate adaptive capacity:	Obligated to a restricted network (or pool) of species, indicating some functional redundancy in those species to which it is obligated
High adaptive capacity:	Diffuse interactions (no obligations)

Module G: Abiotic Niche

G1: Seasonal Phenology

The timing of periodic life cycle events, not directly related to reproduction or movement, that are influenced by seasonal and interannual variations in climate. Seasonal events can include budburst, leaf abscission, timing of developmental cycles, hibernation, etc.

Category	**Category definition**
Low adaptive capacity:	Dependence on environmental cue; species is incapable of adjusting the timing or duration of life-cycle events (i.e., detectable change in cue, but no detectable change in the phenological variable measured); OR timing indirectly dependent and linked to non-environmental cue (e.g., photoperiod), which may result in fitness consequences due to misalignment between life-cycle events and climate
Moderate adaptive capacity:	Moderate dependence on environmental cue; species is capable of adjusting the timing or duration of life-cycle events (i.e., detectable change in cue and species shows some associated change in the phenological variable measured, but change may be less than that of other species in similar habitats or taxonomic groups)
High adaptive capacity:	No dependence on environmental cue; OR dependence on environmental cue, but species is capable of adjusting the timing or duration of life-cycle events (i.e. detectable change in cue and species shows an associated change in the phenological variable measured which is average compared to other species in similar habitats or taxonomic groups; OR timing indirectly dependent and linked to non-environmental cue (e.g. photoperiod) that is not expected to result in fitness consequences due to misalignment between life-cycle events and climate (or misalignment is minimal)

G2: Climatic Niche Breadth

A measure of niche specialization and reflective of the range of abiotic conditions to which a species is adapted, and their degree of flexibility in responding to changing conditions potentially outside of that range.

Category	Category definition
Low adaptive capacity:	Species is completely or almost completely (>90% of occurrences or range) restricted to a particular climatic (or oceanic/hydrological) condition that may be lost or reduced in the assessment area as a result of climate change
Moderately low adaptive capacity:	Species is moderately (50–90% of occurrences or range) restricted to a particular climatic (or oceanic/hydrological) condition that may be lost or reduced in the assessment area as a result of climate change
Moderately high adaptive capacity:	Species is somewhat (10–50% of occurrences or range) restricted to a particular climatic (or oceanic/hydrological) condition that may be lost or reduced in the assessment area as a result of climate change
High adaptive capacity:	Species distribution is not greatly affected by climatic (or oceanic/ hydrological) conditions in the assessment area; OR species occupies habitats that are thought to be not vulnerable to projected climate change; OR species shows a preference for environments at the warmer end of the spectrum (or the leading edge of changing conditions)

G3: Physiological Tolerances

Reflects the degree to which a species (or population) is restricted to a narrow range of abiotic conditions (e.g., temperature, hydrology, or snow conditions). Evaluation often begins with the identification of the differences in sublethal and lethal effects of climate change on the organism. Individuals exposed to climate stressors may reach a state that is beyond their capacity to maintain homeostasis and, consequently, may display changes in behaviors or performances, such as growth rates and reproduction, to defend themselves against stressors. This requires an understanding of thermal limits (or reaction norms), or degree of tolerance of physiological stressors and whether or not the range of conditions causes lethal or sublethal effects. To assess tolerances to future changes, consider how responsive the species has been to previous, or historical, variability.

Category	**Category definition**
Low adaptive capacity:	Range of novel conditions are known to cause lethal effects (intolerable); OR variation in historical conditions for the limiting abiotic factor is highly restricted
Moderate adaptive capacity:	Range of novel conditions unlikely to cause lethal effects (moderately tolerable), although sublethal effects have been observed; OR variation in historical conditions for the limiting abiotic factor is moderate
High adaptive capacity:	Range of novel conditions are not likely to cause sub-lethal or lethal effects (tolerable); OR variation in historical conditions for the limiting abiotic factor is broad and/or extreme events have occurred with no subsequent declines in abundance or extent of occurrence

G4: Behavioral Regulation of Physiology

The ability of individuals to change their behavior in effort to reduce exposure to climate stressors, such as the use of microhabitat features that moderate temperature and extreme conditions (e.g., rock crevices, tree hollows, burrows), or activity periods that limit their exposure to extreme temperatures.

Category	**Category definition**
Low adaptive capacity:	Minimal or no behavioral flexibility and reduction in exposure; species lacks cognitive capacity to enact a behavior, or behavior is canalized and not responsive to environmental influences, or species is restricted in expression of behavior by access to essential resources or other physiological limitations; OR behavior chronically restricts foraging or other essential activities and therefore reduces survivability or fitness
Moderate adaptive capacity:	Moderate behavioral flexibility and reduction in exposure; behavior is infrequent, or is occasionally limited due to restricted access to resources; OR behavior temporarily restricts foraging or reproductive activities, but is not detrimental to survivability or fitness
High adaptive capacity:	High behavioral flexibility and reduction in exposure; behavior is not restricted by access to essential resources and does not substantially limit activities necessary for survival or reproduction

G5: Disturbance Tolerances

Ecological disturbances are events or forces of abiotic or biotic origin that cause mortality to organisms and changes in their spatial patterning. This plays a significant role in shaping the structure and function of ecosystems. The ecological impact of a disturbance is dependent on its intensity, frequency, severity, and spatial extent. Disturbances can include minor events like localized droughts, floods, small wildland fires, and disease outbreaks in plant and animal populations. They may also include major events like hurricanes and broad-scale wind events or forest fires. Though disturbances tend to negatively affect species, some species are disturbance-dependent (or disturbance-adapted) and others can capitalize on opportunities from disturbance events to move into, and gain footholds in, ecosystems that once excluded them.

Category	Category definition
Low adaptive capacity:	Changes in the intensity, frequency, or severity of disturbance events due to climate change are likely to have significantly negative impacts on the species; OR changes in the disturbance regime will be beyond the species tolerance limits and likely to cause lethal effects; OR historical range of variation in patterns of disturbance is highly restricted
Moderate adaptive capacity:	Changes in the intensity, frequency, or severity of disturbance events due to climate change are likely to have moderate impacts on the species; OR changes in the disturbance regime are marginal and not known to be detrimental to the species fitness or survival; OR variation in historical patterns of disturbance is moderate
High adaptive capacity:	Changes in the intensity, frequency, or severity of disturbance events due to climate change are unlikely to have impacts on the species; OR changes in the disturbance regime will be within the species tolerance limits and unlikely to affect species fitness; OR historical patterns of disturbance are highly variable

Module H: Life History

H1: Reproductive Phenology

The timing of reproductive events within a species life cycle that are influenced by seasonal and interannual variations in climate.

Category	Category definition
Low adaptive capacity:	Dependence on environmental cue; species is incapable of adjusting the timing or duration of reproductive events (i.e., detectable change in cue, but no detectable change in the phenological variable measured); OR timing indirectly dependent and linked to non-environmental cue (e.g., resource availability), which may result in fitness consequences due to misalignment between reproductive events and climate
Moderate adaptive capacity:	Moderate dependence on environmental cue; species is capable of adjusting the timing or duration of reproductive events (i.e., detectable change in cue and species shows some associated change in the phenological variable measured, but change may be less than that of other species in similar habitats or taxonomic groups)
High adaptive capacity:	No dependence on environmental cue; OR dependence on environmental cue, but species is capable of adjusting the timing or duration of reproductive events (i.e., detectable change in cue and species shows an associated change in the phenological variable measured, which is average compared to other species in similar habitats or taxonomic groups); OR timing indirectly dependent and linked to non-environmental cue (e.g., resource availability) that is not expected to result in fitness consequences due to misalignment between reproductive events and climate (or misalignment is minimal)

H2: Reproductive Mode

In sexually reproducing organisms, there are multiple modes of reproduction, differentiated based on the relationship between zygote and parents. These include non-viviparous modes: *ovuliparity*, in which fertilization is external and eggs are released into the environment to be fertilized, and *oviparity*, in which fertilization is internal and the male inserts the sperm into the female intermittently or is picked up from the environment, and the female lays eggs. These modes are distinguished from *viviparity*, which covers all modes resulting in live birth. Asexual reproductive modes are captured in factor H3 (Mating System).

Category	Category definition
Low adaptive capacity:	Ovuliparity or broadcast spawning
Moderate adaptive capacity:	Oviparity or direct development or colonial (as in Hymenopterans)
High adaptive capacity:	Viviparity or ovoviviparity (eggs are retained within the mother's body until they are ready to hatch)

H3: Mating System

Group structures within populations related to reproductive behaviors; in animals, this ranges from two-partner (monogamous) systems to promiscuous, multi-partner systems; similarly, in plants, reproductive systems reflect varying degrees of outcrossing, which can range from asexual or cloning systems to cross-fertilization among multiple individuals; these systems contribute to the gene frequency and genetic variability within a population. Although self-fertilization has its advantages and is widespread among hermaphroditic species, it has many consequences for the genetic diversity and evolutionary dynamics of populations. Self-fertilization can increase genetic drift and reduces the efficacy of natural selection.

Option 1: Animals

Category	Category definition
Low adaptive capacity:	Asexual (e.g., parthenogenesis)
Moderately low adaptive capacity:	Monogamy or mixed modes of reproduction (e.g., facultative parthenogenesis in which organisms can produce offspring either sexually or asexually); OR hermaphroditism
Moderately high adaptive capacity	Polygamy (when females have multiple mating partners, it is known as polyandry; when males have multiple mating partners, it is known as polygyny)
High adaptive capacity:	Promiscuity (indiscriminate mating)

Option 2: Plants, fungi, and other sessile species

Category	Category definition
Low adaptive capacity:	Asexual (e.g., apomixis); budding, sporulation, or fragmentation (as in some fungi)
Moderate adaptive capacity:	Self-fertilization (e.g., autogamy) or mixed modes of reproduction (e.g., facultative parthenogenesis in which organisms can produce offspring either sexually or asexually)
High adaptive capacity:	Cross-fertilization (allogamy); sexual reproduction (e.g., via hyphal fusion as in some fungi)

H4: Fecundity

The total number of offspring, seed sets, or asexual propagules produced, on average, by reproductive individuals of the species (or population) in a lifetime (i.e., lifetime average).

Category	Category definition
Low adaptive capacity:	One or two offspring or propagules
Moderate adaptive capacity:	Few offspring or propagules (3–10)
High adaptive capacity:	Many offspring or propagules (>10)

H5: Parity

The number of times an organism reproduces within its lifetime (i.e., reproductive rate). In animals, species are either semelparous and have a single reproductive event per lifetime, or iteroparous with multiple reproductive cycles. In plants, species are either monocarpic (single flowering cycle), plietesial (grow for a number of years then flower gregariously or synchronously once), or polycarpic (multiple flowering cycles).

Option 1: Animals

Category	Category definition
Low adaptive capacity:	Semelparous; single reproductive event per lifetime
Moderate adaptive capacity:	NA
High adaptive capacity:	Iteroparous; multiple reproductive cycles per lifetime

Option 2: Plants

Category	Category definition
Low adaptive capacity:	Monocarpic; single reproductive event per lifetime
Moderate adaptive capacity:	Plietesial
High adaptive capacity:	Polycarpic; multiple reproductive events per lifetime

H6: Sex Ratio

Spending equal amounts of resources to produce offspring of either sex is an evolutionarily stable strategy. For species where the cost of successfully raising one offspring is roughly the same regardless of its sex, this translates to an approximately equal sex ratio and is common in sexually reproducing species according to Fisher's principle, wherein parents will invest their resources equally between each sex of offspring because each sex supplies exactly half the genes of all future generations. However, many parthenogenic species and some colonial insect species can either permanently or periodically deviate from the 1:1 strategy and often exhibit female-biased sex ratios. Reptile species that exhibit environmental sex determination also tend towards skewed sex ratios.

Category	Category definition
Low adaptive capacity:	Skewed (female- or male-biased; common in small populations of certain taxa) with known or expected consequences to local mate availability, male-to-male aggression, male-to-female harassment, or other disruptions to pair-bond formation or reproductive output
Moderate adaptive capacity:	Capable of facultative adjustments to mating systems to account for skewed adult sex ratios (as is the case in some species with female-biased populations); OR species is capable of hermaphroditism
High adaptive capacity:	Balanced (1:1); OR temporary deviations from 1:1 sex ratio have no known or expected consequences on mate availability, intraspecific interactions, pair-bond formation, or reproductive output

H7: Sex Determination

In many species, sex determination is genetic, wherein males and females have different alleles (or genes) that specify their sexual morphology. In animals, this is often accompanied by chromosomal differences or haplodiploidy. With haplodiploidy, females arise from a fertilized egg (diploid) whereas males result from an unfertilized egg (haploid). In other cases, sex is determined by environmental variables (such as temperature) and populations may therefore be susceptible to skewed sex ratios (e.g., if ambient temperature increases). For species that reproduce via parthenogenesis, the sex of offspring is determined by the same method sex is determined in the species itself: for organisms where sex is determined by chromosomes, like the XX female and XY male chromosomes in some insects, fish and reptiles, females will only produce XX female offspring. For organisms where females have ZW sex chromosomes (such as in snakes and birds), all offspring produced will either be ZZ (male) or much more rarely if viable, WW (female).

Category	**Category definition**
Low adaptive capacity:	Temperature- or environment-dependent
Moderate adaptive capacity:	Haplodiploidy; OR temperature-induced sex reversal as in some reptiles with chromosomal sex determination; OR parthenogenesis (including facultative parthenogenesis); OR asexually reproducing hermaphrodites
High adaptive capacity:	Chromosomal

H8: Parental Investment

Any parental expenditure (time, energy, etc.) that benefits the offspring at a cost to parents' ability to invest in other components of their own fitness is considered a form of reproductive success (note, this factor is not applicable to plants and other primary producers). Parental Investment represents one of many life-history optimization tradeoffs reflective of the cost of reproduction. Individuals are limited in the degree to which they can devote time and resources to producing and raising their young, and such expenditure may be detrimental to their own future condition, survival, and reproductive output. However, such expenditure is typically beneficial to the offspring, enhancing their condition, survival, and future reproductive success. Parental Investment relates to parental energetic costs (as opposed to offspring survivorship, which is captured in factor H2 (Reproductive Mode).

Category	**Category definition**
Low adaptive capacity:	Altricial (young are hatched or born in an undeveloped state and require care and feeding by the parent[s])
Moderate adaptive capacity:	Semi-precocial (dependent on parents for food) or semi-altricial; OR Altruistic care of young by non-reproducing individuals within the population (e.g., sterile worker bees)
High adaptive capacity:	Precocial (young are relatively mature and mobile from the moment of birth or hatching and capable of feeding themselves)

Module I: Demography

I1: Life Span

Also referred to as longevity; the period between birth and death for the individual, or the average length of life or life expectancy for a population.

Category	Category definition
Low adaptive capacity:	≥25 years
Moderately low adaptive capacity:	10–25 years
Moderately high adaptive capacity:	1–10 years
High adaptive capacity:	≤1 year

I2: Generation Time

Also referred to as generation interval; average time between two consecutive generations in the lineages of a population. Generation Time can be measured as the mother–daughter distance (the average age of mothers at birth of their daughters). Species with longer generation times typically have slower life histories and lower reproductive output.

Category	Category definition
Low adaptive capacity:	≥25 years
Moderately low adaptive capacity:	10–25 years
Moderately high adaptive capacity:	1–10 years
High adaptive capacity:	≤1 year

I3: Age of Sexual Maturity

Also referred to as age at recruitment or age of first reproduction; time to reproductive maturation, relative to overall lifespan. Age of Sexual Maturity is another life history optimization tradeoff; early reproduction lowers the chance of dying without offspring and increases the number of lifetime reproductive attempts (thereby increasing fitness), but breeding investment in early life can reduce survival probability and accelerate senescence later in life. Therefore, Age of Sexual Maturity, when evaluated in the context of fecundity, parity, and parental investment, is an indicator of reproductive fitness.

Category	Category definition
Low adaptive capacity:	Delayed (late relative to lifespan)
Moderate adaptive capacity:	Intermediate (about halfway through lifetime)
High adaptive capacity:	Rapid (early relative to lifespan)

I4: Age Structure

A summary of the number of individuals of each age (or age class) in a population. Age Structure is useful in understanding and predicting population growth: if most individuals in a population are below the age of first reproduction, then the population is likely to grow, but if most individuals are beyond reproductive age, then the population would be expected to shrink. This factor is likely not applicable to annual plants or most insects.

Category	Category definition
Low adaptive capacity:	More old (higher proportion of population is beyond reproductive age)
Moderate adaptive capacity:	Balanced (age classes are roughly equal)
High adaptive capacity:	More young (higher proportion of population is below first age of reproduction)

I5: Recruitment

Proportion of juveniles surviving to adulthood (maturity) in a population. Recruitment can be an important factor in predicting future population growth potential; high recruitment may increase a species' current and future abundance within a system, whereas low recruitment can lead to reduced current and future abundance.

Category	Category definition
Low adaptive capacity:	Small proportion or None
Moderate adaptive capacity:	Approximately half; OR variability in recruitment, such as for r-selected species that exhibit asynchronous and highly variable recruitment and mortality from year to year and across life stages
High adaptive capacity:	Large proportion or all juveniles

Module J: Threat Multipliers (other extrinsic factors that affect climate change vulnerability)

J1: Topographic Barriers to Movement

Factors J1 and J2 assess the degree to which natural (e.g., topographic, geographic, ecological) or anthropogenic barriers limit a species' ability to shift its range in response to climate change. Barriers are defined here as features or areas that completely or almost completely prevent movement or dispersal of the species (currently and for the foreseeable future). Species for which barriers would inhibit distributional shifts with climate change-caused shifts in climate envelopes likely are more vulnerable to climate change than are species whose movements are not affected by barriers. Barriers must be identified for each species (but often are the same for a group of closely related species). Natural and anthropogenic barriers are defined for many species and taxonomic groups in NatureServe's Element Occurrence Specifications (viewable in the Population/Occurrence Delineation Module of species accounts on NatureServe Explorer (https://explorer.natureserve.org/pro/Welcome), but usually these can be determined by considering a species' basic movement capacity and ecological tolerances. Also see The Nature Conservancy's Resilient Land Mapping Tool (https://www.maps.tnc.org/resilientland/#/explore) for exploring connectivity and barriers to inform this assessment.

The distinction between a barrier and unsuitable habitat sometimes may be unclear; in these cases, assume the feature or area is unsuitable habitat (habitat through which the species can disperse or move but that does not support reproduction or long-term survival) and score the species here and/or in factor D2 (Dispersal Distance) as appropriate. Note that caves are considered under factor C3 (Habitat Specialization), and not here where the focus is on barriers that affect the wide array of non-subterranean species.

Category	Category definition
Greatly Increases Vulnerability:	Barriers completely, or almost completely, surround the current distribution such that the species' range in the assessment area is unlikely to be able to shift significantly with climate change, or the direction of climate change-caused shift in the species' favorable climate envelope is fairly well understood and barriers prevent a range shift in that direction. See *Neutral* for species in habitats not vulnerable to climate change. *Examples for topographic barriers:* lowland terrestrial species completely surrounded by high mountains (or bordered closely and completely on the north side by high mountains); cool-water stream fishes for which barriers would completely prevent access to other cool-water areas if the present occupied habitat became too warm as a result of climate change; most nonvolant species that exist only on the south side of a very large lake in an area where habitats are expected to shift northward with foreseeable climate change.

Increases Vulnerability:	Barriers border the current distribution such that climate change-caused distributional shifts in the assessment area are likely to be greatly but not completely or almost completely impaired. *Examples for topographic barriers:* certain lowland plant or small mammal species whose ranges are mostly (50-90%) bordered by high mountains or a large lake.
Somewhat Increases Vulnerability:	Barriers border the current distribution such that climate change-caused distributional shifts in the assessment area are likely to be significantly but not greatly or completely impaired. *Examples for topographic barriers:* certain lowland plant or small mammal species whose ranges are partially but not mostly bordered by high mountains or a large lake.
Neutral:	Significant barriers do not exist for this species, OR small barriers exist in the assessment area but likely would not significantly impair distributional shifts with climate change, OR substantial barriers exist but are not likely to contribute significantly to a reduction or loss of the species' habitat or area of occupancy with projected climate change in the assessment area.

J2: Anthropogenic Barriers to Movement

Factors J1 and J2 assess the degree to which natural (e.g., topographic, geographic, ecological) or anthropogenic barriers limit a species' ability to shift its range in response to climate change. Barriers are defined here as features or areas that completely or almost completely prevent movement or dispersal of the species (currently and for the foreseeable future). Species for which barriers would inhibit distributional shifts with climate change-caused shifts in climate envelopes likely are more vulnerable to climate change than are species whose movements are not affected by barriers. Barriers must be identified for each species (but often are the same for a group of closely related species). Natural and anthropogenic barriers are defined for many species and taxonomic groups in NatureServe's Element Occurrence Specifications (viewable in the Population/Occurrence Delineation Module of species accounts on NatureServe Explorer (https://explorer.natureserve.org/pro/Welcome), but usually these can be determined by considering a species' basic movement capacity and ecological tolerances. Also see The Nature Conservancy's Resilient Land Mapping Tool (https://www.maps.tnc.org/resilientland/#/explore) for exploring connectivity and barriers to inform this assessment.

The distinction between a barrier and unsuitable habitat sometimes may be unclear; in these cases, assume the feature or area is unsuitable habitat (habitat through which the species can disperse or move but that does not support reproduction or long-term survival) and score the species here and/or in factor D2 (Dispersal Distance) as appropriate. Note that caves are considered under factor C3 (Habitat Specialization), and not here where the focus is on barriers that affect the wide array of non-subterranean species.

Category	Category definition
Greatly Increases Vulnerability:	Barriers completely OR almost completely surround the current distribution such that the species' range in the assessment area is unlikely to be able to shift significantly with climate change, or the direction of climate change-caused shift in the species' favorable climate envelope is fairly well understood and barriers prevent a range shift in that direction. See *Neutral* for species in habitats not vulnerable to climate change. *Examples for anthropogenic barriers:* species limited to small habitats within intensively developed urban or agricultural landscapes through which the species cannot pass; a specific example of this category is provided by the Quino checkerspot butterfly (*Euphydryas editha quino*), a resident of northern Baja California and southern California; warming climates are forcing this butterfly northward, but urbanization in San Diego blocks its movement (Parmesan 1996, Nature 382:765).
Increases Vulnerability:	Barriers border the current distribution such that climate change-caused distributional shifts in the assessment area are likely to be greatly but not completely or almost completely impaired. *Examples for anthropogenic barriers:* most streams inhabited by a fish species have dams that would prevent access to suitable habitat if the present occupied habitat became too warm as a result of climate change; intensive urbanization surrounds 75% of the range of a salamander species.

Somewhat Increases Vulnerability:	Barriers border the current distribution such that climate change-caused distributional shifts in the assessment area are likely to be significantly but not greatly or completely impaired. *Examples for anthropogenic barriers:* 10-50% of the margin of a plant species' range is bordered by intensive urban development; 25% of the streams occupied by a fish species include dams that are likely to impede range shifts driven by climate change.
Neutral:	Significant barriers do not exist for this species, OR small barriers exist in the assessment area but likely would not significantly impair distributional shifts with climate change, OR substantial barriers exist but are not likely to contribute significantly to a reduction or loss of the species' habitat or area of occupancy with projected climate change in the assessment area.

J3: Land-use Change

This factor addresses other anthropogenic stressors that are projected to cause habitat change or loss within the species' range in the assessment area, such as urbanization, agriculture, livestock grazing, mining, logging, energy development, road construction and other infrastructure development, or water diversion or extraction. Projections should consider a time span corresponding to 3 generations or 10 years, whichever is longer.

Category	Category definition
Greatly Increases Vulnerability:	Changes that will reduce or degrade more than 50% of existing habitat
Increases Vulnerability:	Changes that will reduce or degrade between 31-50% of existing habitat
Somewhat Increases Vulnerability:	Changes that will reduce or degrade between 10-30% of existing habitat
Neutral:	Changes that will reduce or degrade less than 10% of existing habitat or increase the availability of suitable habitat

J4: Other anthropogenic threats

This factor addresses other anthropogenic stressors within the species' range in the assessment area that do not directly cause habitat change or loss, such as harvest, persecution, pollution (land, water, light/sound), and disturbance (such as through recreational or work activities) but that are predicted to increase in magnitude due to climate change. Projections of threat impacts on population should consider a time span corresponding to 3 generations or 10 years, whichever is longer. Threats such as those from invasive species, competitors, or predators are considered in factor J5 (other biological threats).

Category	**Category definition**
Greatly Increases Vulnerability:	Threats are projected to cause a population decrease of more than 50%
Increases Vulnerability:	Threats are projected to cause a population decrease of 31-50%
Somewhat Increases Vulnerability:	Threats are projected to cause a population decrease 10-30%
Neutral:	Threats are projected to cause a population decrease of less than 10%

J5: Other Biological Threats

This factor addresses biological threats such as invasive species, disease, competition, parasitism, herbivory, and predation that are predicted to increase in prevalence with climate change. We differentiate between climate change impacts on biological threats (as described in this factor) vs. impacts of biological threats on the target species' ability to adapt to climate change (as described in Factor F1: Enemies). Examples of other biological threats include the chytrid fungal pathogen that can become more harmful to frogs because of climate change or sudden oak death in California caused by a pathogen that is invasive under favorable climate conditions. Also, species may suffer when competitors are favored by both changing climates and the effects these climates have on disturbance regimes. However, in some cases climate change may limit the spread of particular invasive species . To score this factor, some indication is needed that the biological threat(s) is favored by projected future climates.

Category	Category definition
Greatly Increases Vulnerability:	Catastrophic loss is predicted for the species due to an invasive species, competitor, pathogen or other natural enemy that is likely to increase in distribution, abundance, or impact as a result of climate change.
Increases Vulnerability:	Species is negatively affected to a high degree by an invasive species, competitor, pathogen or other natural enemy that is likely to increase in distribution, abundance, or impact as a result of climate change. Example: The cold-sensitive non-native hemlock woolly adelgid commonly causes a high level of mortality in eastern hemlock (*Tsuga canadensis*), and the distribution/abundance/impact of the adelgid may increase in areas where winter temperatures become milder.
Somewhat Increases Vulnerability:	Species is negatively affected to a moderate degree by an invasive species, competitor, pathogen or natural enemy that is likely to increase in distribution, abundance, or impact as a result of climate change.
Neutral:	There is no indication that the species is currently or in the foreseeable future likely to be significantly affected by an invasive species, competitor, pathogen or other natural enemy that is likely to increase in distribution, abundance, or impact as a result of climate change; OR the negative impact of these enemies is likely to decrease with climate change. Example: A warmer/drier climate may reduce the negative impact of certain fungal pathogens that depend/thrive on relatively cold/moist conditions.

Module K: Documented or Modeled Response to Climate Change

Module K is optional; evaluate these factors for the specific taxonomic scale and geographical area under consideration, if possible.

K1: Documented Response to Recent Climate Change

This factor pertains to the degree to which a species is known to have responded to recent climate change based on published accounts in the peer-reviewed literature. Time frame for the documented response is 10 years or three generations, whichever is longer. Some examples include population declines due to phenological mismatches between species and critical food or pollinator resources, e.g., great tits (*Parus major*) or pied flycatchers (*Ficedula hypoleuca*) with winter moth (*Operophtera brumata*) caterpillars, or honey-buzzards (*Pernis apivorus*) with wasps. Note that not all responses to climate change necessarily indicate vulnerability. Species that respond to climate change by shifting (but not contracting) their range, for example, show adaptability to climate change and should be scored as *Neutral* for this factor. Similarly, species that respond by changing their phenology (without a related decline in population) should also be scored as *Neutral*.

Category	**Category definition**
Greatly Increases Vulnerability:	Distribution or abundance undergoing major reduction (>70% over 10 years or three generations) believed to be associated with climate change.
Increases Vulnerability:	Distribution or abundance undergoing moderate reduction (30-70% over 10 years or three generations) believed to be associated with climate change.
Somewhat Increases Vulnerability:	Distribution or abundance undergoing small but measurable reductions (10-30% over 10 years or three generations) believed to be associated with climate change.
Neutral:	Distribution and abundance not known to be decreasing with climate change. Includes species undergoing range shifts without loss of distributional area or species undergoing changes in phenology but no net loss in range size or population size. Includes species in which climate change is documented to be causing an increase in range size or abundance.

K2: Modeled Future (e.g., mid-century) Change in Range or Population Size

This factor can include both distribution models and/or population models. When sourcing information from the literature, predictions should be based on the climate scenario(s) for approximately mid-century used in the assessment and follow best practices from the peer-reviewed literature. Examples include (a) range shift projections based on climate envelope models; (b) phenological changes that are likely to result in a mismatch with critical dietary, pollination, or habitat resources ; or (c) documented narrow temperature tolerances and thermal maxima/minima.

Category	Category definition
Greatly Increases Vulnerability:	Predicted future range disappears entirely from the assessment area; OR predicted future abundance declines to zero as a result of climate change processes
Increases Vulnerability:	Predicted future range represents 50-99% decrease relative to current range within the assessment area; OR predicted future abundance represents 50-99% decrease associated with climate change processes
Somewhat Increases Vulnerability:	Predicted future range represents a 20-50% decrease relative to current range within the assessment area; OR predicted future abundance represents 20-50% decrease associated with climate change processes
Neutral:	Predicted future range represents an increase, no change, or a decrease of less than a 20% relative to current range within the assessment area; OR predicted future abundance increases, remains stable, or decreases <20% as a result of climate change processes

K3: Overlap of Modeled Future (e.g., mid-century) Range with Current Range

Distribution models of current and projected future distributions should meet best practices described in the notes for factor K2. Range overlap is calculated as the percent of the current range represented by an intersection of the predicted future and current distributions. If factor K2 is coded as Greatly Increases Vulnerability, this factor should be skipped to avoid double-counting model results.

Category	Category definition
Greatly Increases Vulnerability:	There is no overlap between the current and predicted future range within the assessment area
Increases Vulnerability:	Predicted future range overlaps the current range by 30% or less within the assessment area
Somewhat Increases Vulnerability:	Predicted future range overlaps the current range by 30-60% within the assessment area
Neutral:	Predicted future range overlaps the current range by > 60% within the assessment area

K4: Occurrence of Protected Areas in Modeled Future (e.g., mid-century) Distribution

“Protected area" refers to existing parks, refuges, wilderness areas, and other designated conservation areas that are relatively invulnerable to outright habitat destruction from human activities and that are likely to provide suitable conditions for the existence of viable populations of the species. Models of current and projected future distributions should meet best practices described in the notes for K2. Modeled future distribution may refer to a single season (e.g., breeding season distribution or winter distribution) for migratory species. This factor considers the species’ occurrence and prevalence of protected areas within the assessment area only.

Category	Category definition
Increases Vulnerability:	<5% of the modeled future distribution within the assessment area is encompassed by one or more protected areas.
Somewhat Increases Vulnerability:	5-30% of the modeled future distribution within the assessment area is encompassed by one or more protected areas.
Neutral:	>30% of the modeled future distribution within the assessment area is encompassed by one or more protected areas.

References

Abatzoglou, J. T., & Brown, T. J. (2012). A comparison of statistical downscaling methods suited for wildfire applications. *International Journal of Climatology*, *32*(5), 772–780. https://doi.org/10.1002/joc.2312

Abatzoglou, J. T., & Kolden, C. A. (2011). Climate Change in Western US Deserts: Potential for Increased Wildfire and Invasive Annual Grasses. *Rangeland Ecology & Management*, *64*(5), 471–478. https://doi.org/10.2111/REM-D-09-00151.1

Bradley, B. A., Blumenthal, D. M., Wilcove, D. S., & Ziska, L. H. (2010). Predicting plant invasions in an era of global change. *Trends in Ecology & Evolution*, *25*(5), 310–318. https://doi.org/10.1016/j.tree.2009.12.003

Calosi, P., Bilton, D. T., & Spicer, J. I. (2007). Thermal tolerance, acclimatory capacity and vulnerability to global climate change. *Biology Letters*, *4*(1), 99–102. https://doi.org/10.1098/rsbl.2007.0408

Deutsch, C. A., Tewksbury, J. J., Huey, R. B., Sheldon, K. S., C. K. Ghalambor, Haak, D. C., & Martin, P. R. (2008). Impacts of climate warming on terrestrial ectotherms across latitude. *Proceedings of the National Academy of Sciences*, *105*(18), 6668–6672. https://doi.org/10.1073/pnas.0709472105

Dukes, J. S., Chiariello, N. R., Loarie, S. R., & Field, C. B. (2011). Strong response of an invasive plant species (Centaurea solstitialis L.) to global environmental changes. *Ecological Applications*, *21*(6), 1887–1894. https://doi.org/10.1890/11-0111.1

Grossman, J. D., & Rice, K. J. (2014). Contemporary evolution of an invasive grass in response to elevated atmospheric CO2 at a Mojave Desert FACE site. *Ecology Letters*, *17*(6), 710–716. https://doi.org/10.1111/ele.12274

Hegewisch, K.C., Abatzoglou, J.T., Chegwidden,O., & Nijssen, B., 'Climate Mapper' web tool. Climate Toolbox (https://climatetoolbox.org/) accessed on 12/13/23.

IUCN. (2012). *IUCN Red List categories and criteria, version 3.1, second edition*. IUCN. https://portals.iucn.org/library/node/10315

IUCN Standards and Petitions Committee. (2024). *Guidelines for Using the IUCN Red List Categories and Criteria. Version 16.* Prepared by the Standards and Petitions Committee. https://www.iucnredlist.org/documents/RedListGuidelines.pdf.

Meentemeyer, R. K., Cunniffe, N. J., Cook, A. R., Filipe, J. A. N., Hunter, R. D., Rizzo, D. M., & Gilligan, C. A. (2011). Epidemiological modeling of invasion in heterogeneous landscapes: Spread of sudden oak death in California (1990–2030). *Ecosphere*, *2*(2), art17. https://doi.org/10.1890/ES10-00192.1

Pintó-Marijuan, M. & S. Munné-Bosch. (2013). Ecophysiology of invasive plants: Osmotic adjustment and antioxidants. *Trends in Plant Science*, *18*(12), 660–666. https://doi.org/10.1016/j.tplants.2013.08.006

Pounds, A. J., Bustamante, M. R., Coloma, L. A., Consuegra, J. A., Fogden, M. P. L., Foster, P. N., La Marca, E., Masters, K. L., Merino-Viteri, A., Puschendorf, R., Ron, S. R., Sánchez-Azofeifa, G. A., Still, C. J., & Young, B. E. (2006). Widespread amphibian extinctions from epidemic disease driven by global warming. *Nature*, *439*(7073), 161–167. https://doi.org/10.1038/nature04246

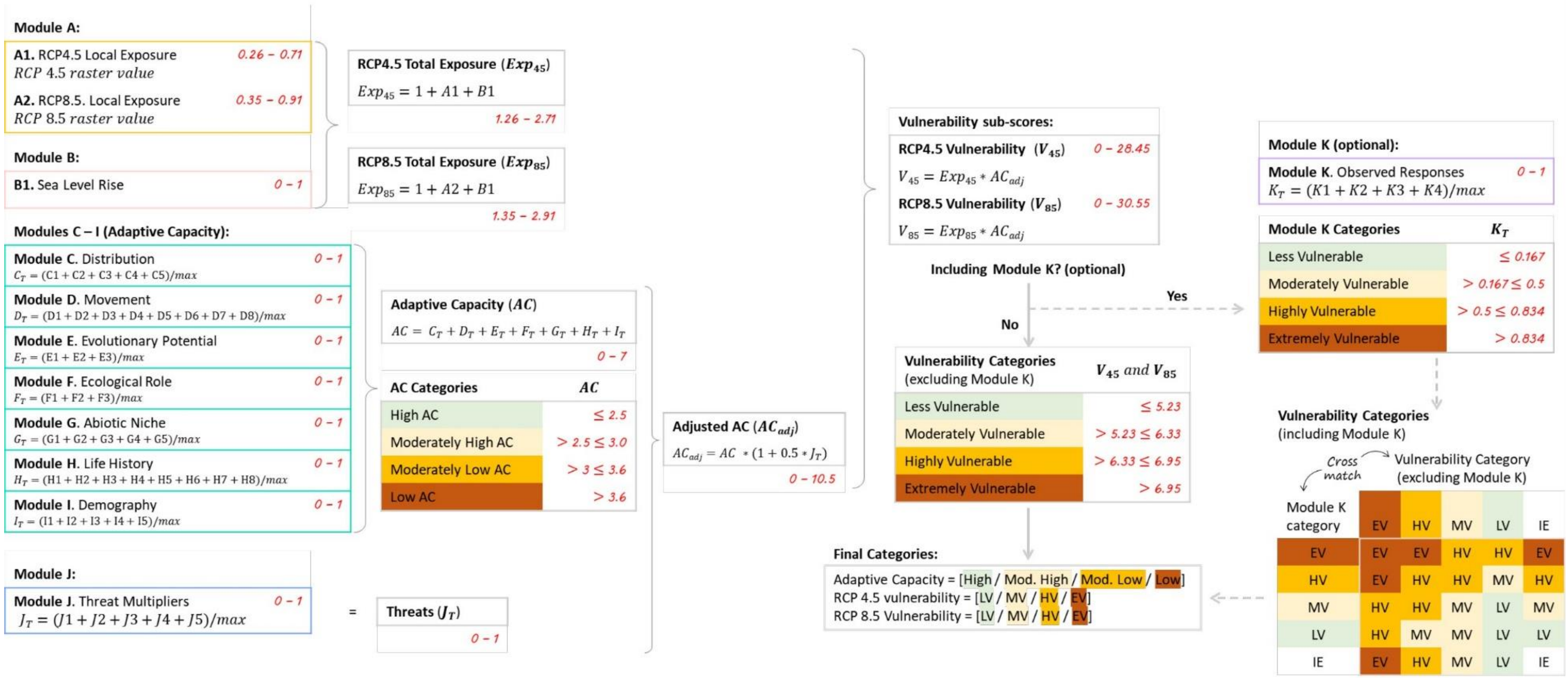
Thurman, L. L., Stein, B. A., Beever, E. A., Foden, W., Geange, S. R., Green, N., Gross, J. E., Lawrence, D. J., LeDee, O., Olden, J. D., Thompson, L. M., & Young, B. E. (2020). Persist in place or shift in space? Evaluating the adaptive capacity of species to climate change. *Frontiers in Ecology and the Environment*, *18*(9), 520–528. https://doi.org/10.1002/fee.2253

Visser, M. E., & Both, C. (2005). Shifts in phenology due to global climate change: The need for a yardstick. *Proceedings of the Royal Society B: Biological Sciences*, *272*(1581), 2561–2569. https://doi.org/10.1098/rspb.2005.3356

Young, B. E., Dubois, N. S., & Rowland, E. L. (2015). Using the climate change vulnerability index to inform adaptation planning: Lessons, innovations, and next steps. *Wildlife Society Bulletin*, *39*(1), 174–181. https://doi.org/10.1002/wsb.478

Young, B. E., Hall, K. R., Byers, E., Gravuer, K., Hammerson, G., Redder, A., & Szabo, K. (2012). 7. Rapid Assessment of Plant and Animal Vulnerability to Climate Change. In J. F. Brodie, E. S. Post, & D. F. Doak (Eds.), *Wildlife Conservation in a Changing Climate* (pp. 129–150). University of Chicago Press. https://doi.org/10.7208/9780226074641-007

Appendix A: Algorithm



Appendix B: Sea Level Rise

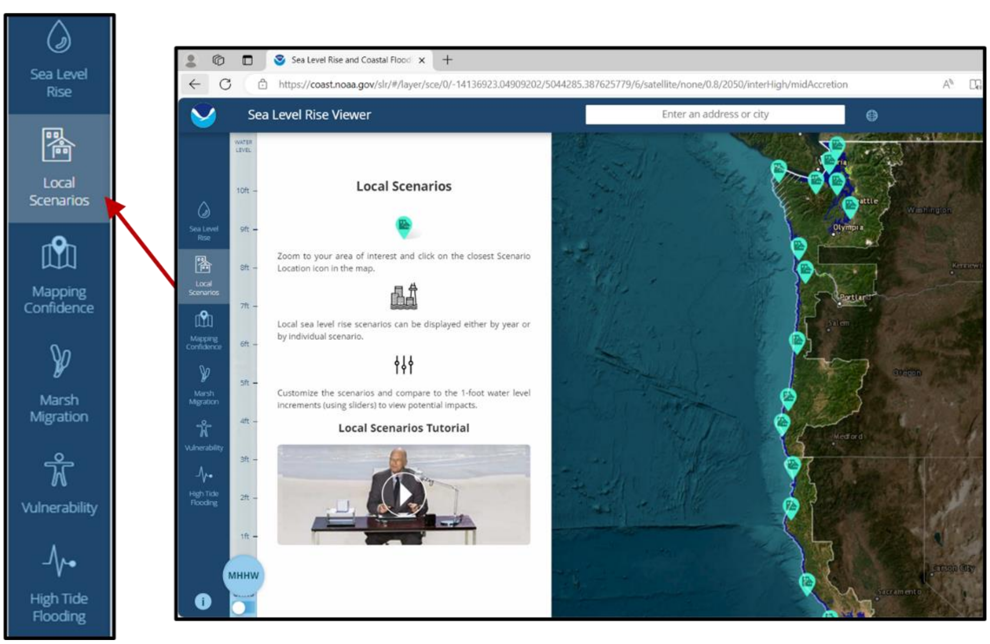
Estimating Module B exposure with the NOAA Sea Level Rise Viewer

Overview

1. Go to https://coast.noaa.gov/slr/.
2. Click "Get Started".
3. On map, zoom in to your area of interest.
4. Select "Local Scenarios" from the left bar.
5. Select the tidal gauge (teal building icon) nearest your area of interest on the map. Note that you may need to zoom out to see nearest gauge.
6. Select "VIEW BY YEAR" from the top of the new panel.
7. On the right-hand side of the panel, set year to **2060** with the slider.
8. On the left-hand side of the panel, slide the selector up the vertical ruler to a value between the **Intermediate high** and **Intermediate low** estimates. Note that the slider only moves in whole unit steps (e.g. 1 ft increments) and will not match estimates exactly. Simply, get as close as possible. The map will now show you what areas would be underwater.
9. Toggle slider between the current sea level (Current MHHW) and future sea level rise to see change in inundated area.

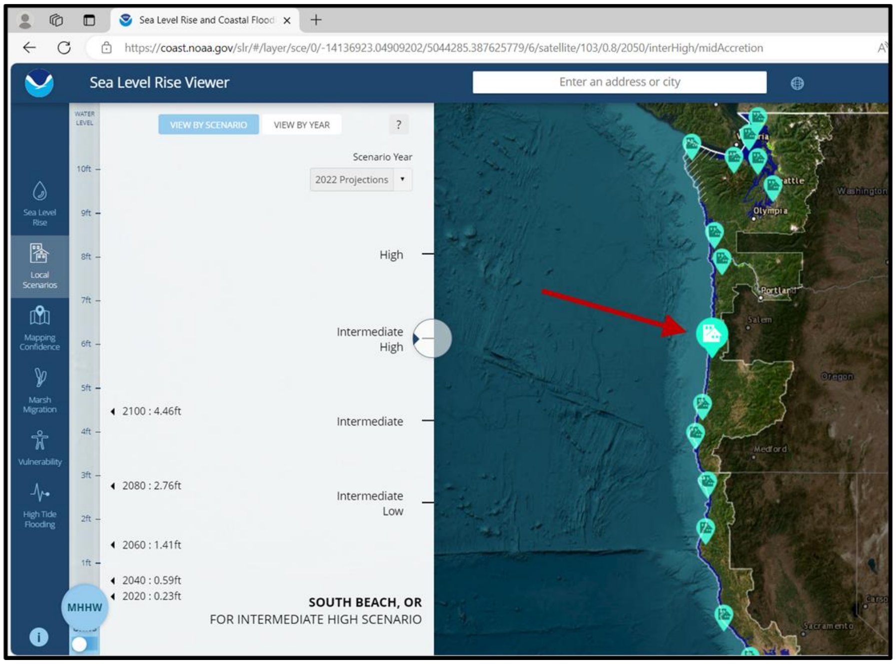
Step-by-Step Instructions

1. Go to https://coast.noaa.gov/slr/
2. Select the green "Get Started" rectangle.
3. Zoom to your area of interest.
4. Select "Local Scenarios" from the left bar.

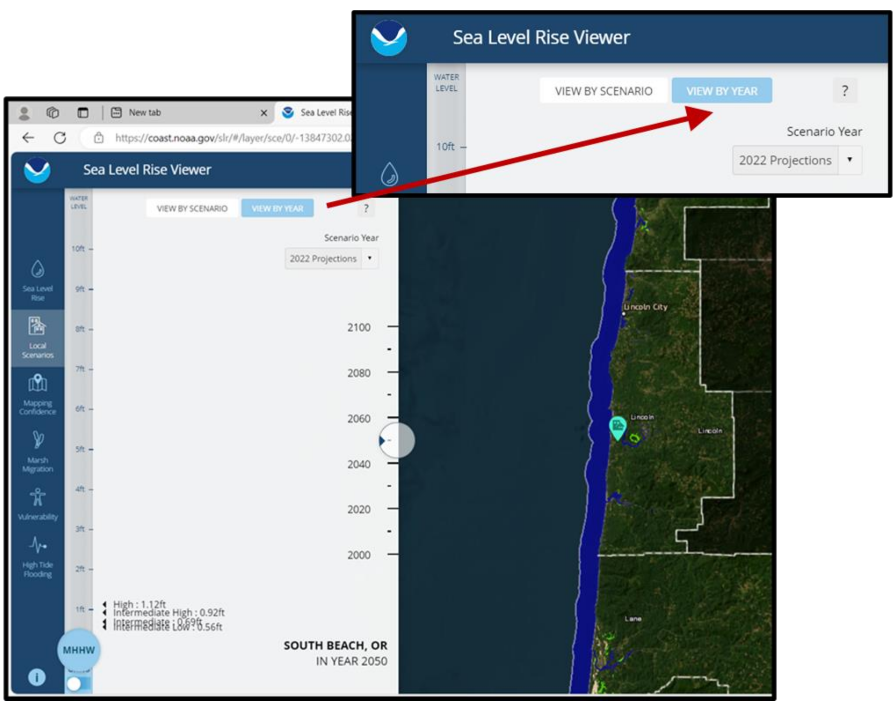


5. Select the tidal gauge (teal building icon) nearest your area of interest on the map.

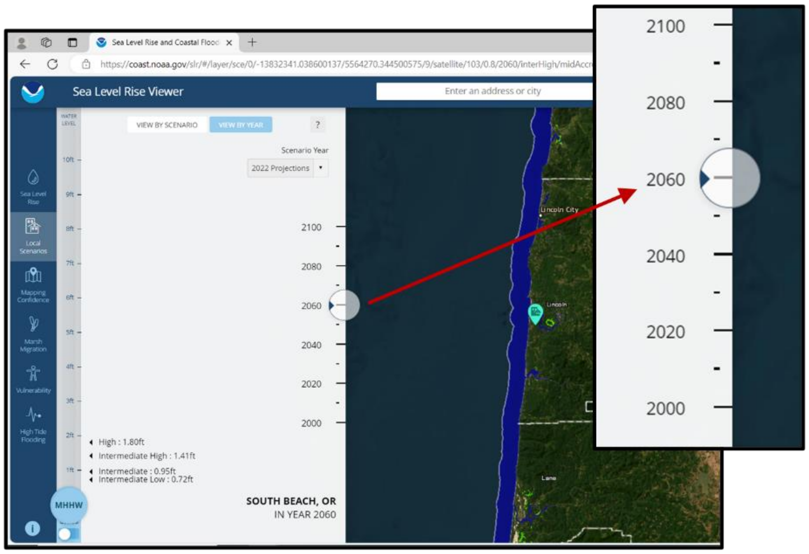
Note, you may need to zoom out to find the nearest tidal gauge.

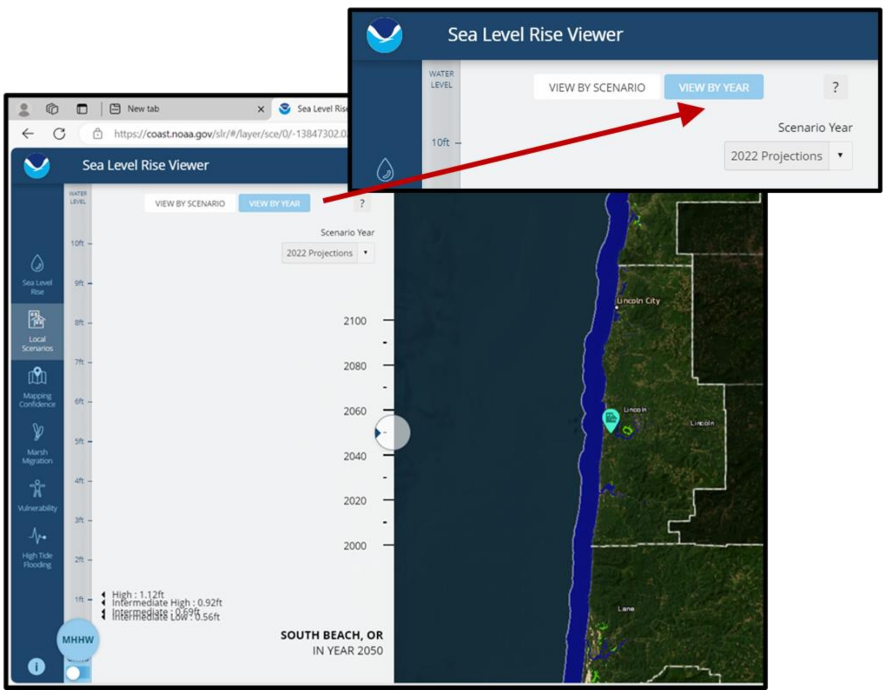


6. A panel will pop up on the left side of the window. Select "VIEW BY YEAR" from the top of the new panel.

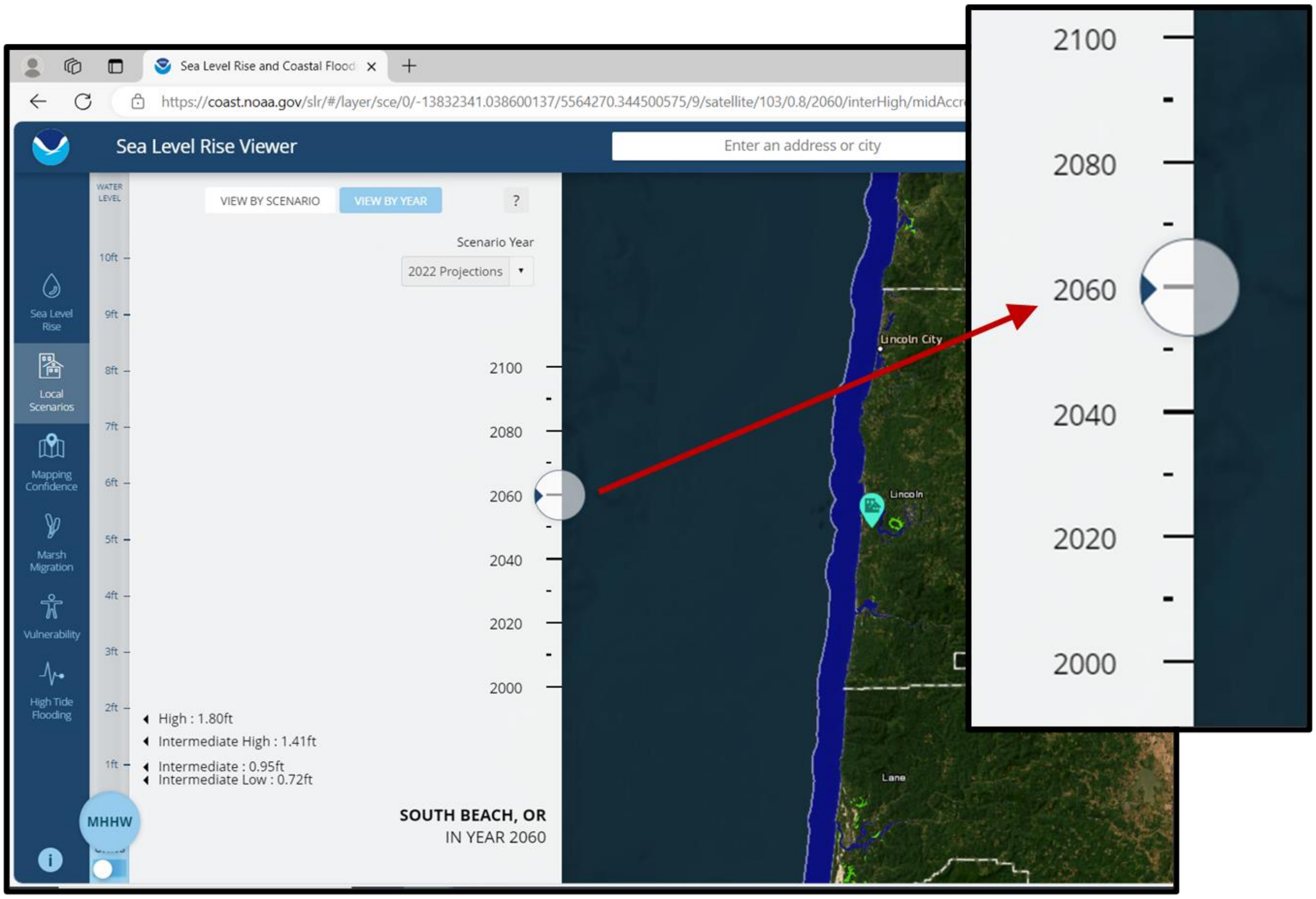


a. Set year to 2060 with the slider on the right side of the panel.

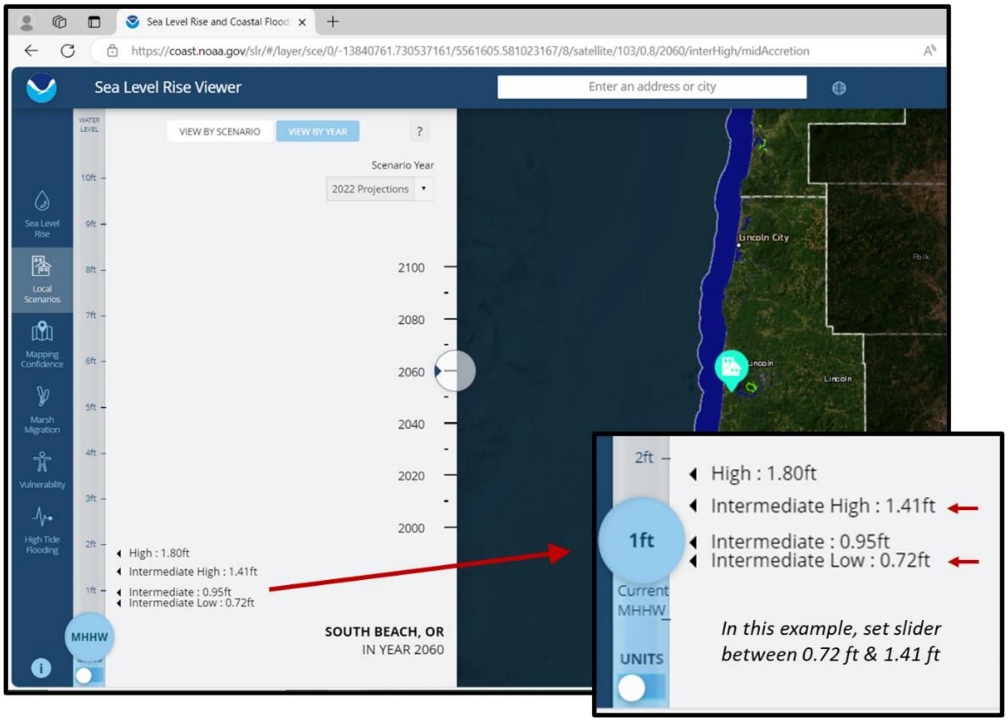




Set year to 2060 with the slider on the right side of the panel.



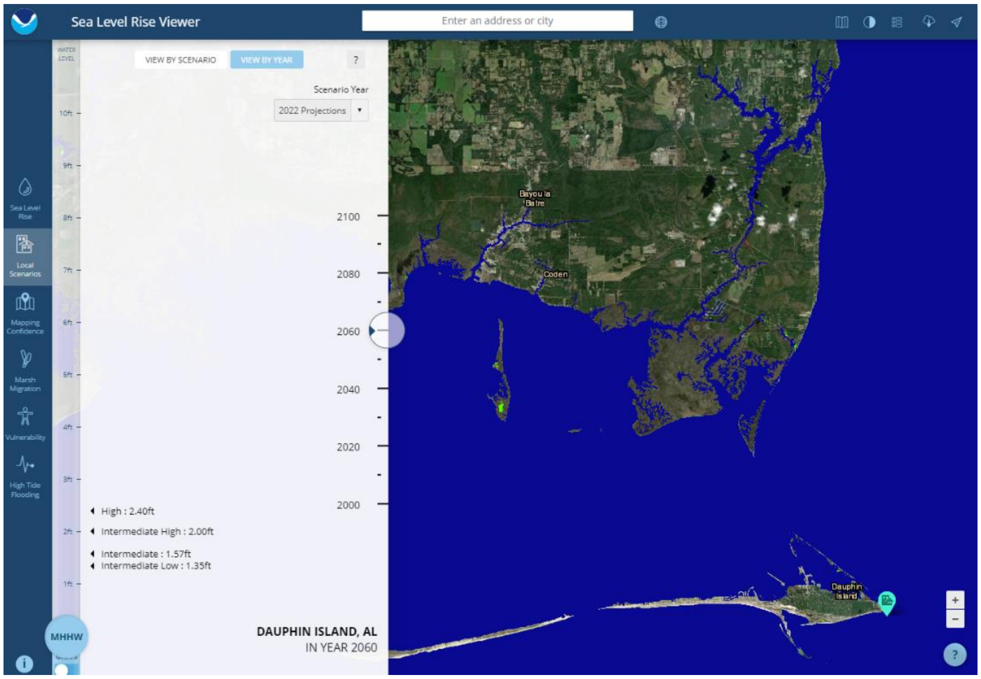
7. On the left side of the panel, slide the blue selector icon labeled 'MHHW' up the vertical ruler to a value between the **Intermediate high** and **Intermediate low** estimates. The map will now show you what areas would be underwater.
   Note, the slider only moves in whole unit steps (e.g. 1 ft increments) and will not match estimates exactly. Simply, get as close as possible. The slider label will change to reflect current value selected.



8. Toggle slider between the current sea level (Current MHHW) and future sea level rise to see change.

Example: Dauphin Island, AL

Current shoreline boundaries.



Mid-century: Estimated areas underwater with 2 ft of sea level rise by 2060.