# INCORPORATING CLIMATE CHANGE SCENARIOS


# INTO InVEST AND RIOS

Last updated: January 11, 2016

Edited by Lisa Mandle
Contributing authors: Adrian L. Vogl, Perrine Hamel, Jess Silver, Robert Griffin, Spencer A. Wood, Gregg Verutes, Lauren Rogers, Becky Chaplin-Kramer and Katie K. Arkema

## Contents

## Introduction

We created this document to provide practical suggestions for and examples of incorporating climate change scenarios into ecosystem service assessments using the Natural Capital Project's InVEST models and RIOS spatial prioritization tool. Our suggestions are based on the inputs that are most likely to vary with climate change and that are feasible to model based on available science. Not all the possibilities we present here may be relevant or practical for every application of InVEST or RIOS, and we may have overlooked factors that are important to consider for particular decision contexts or locations. This document is a work in progress, so stay tuned for updates as new data, models and example applications become available.

## Key aspects of climate change to consider

***For terrestrial and freshwater services***: changes in mean temperature (warming trend) and temperature extremes; changes in mean precipitation, precipitation seasonality and extreme precipitation events; increased carbon dioxide concentration (and potential carbon dioxide fertilization)

***For marine and coastal services***: changes in temperature and temperature extremes; sea level rise; changes in frequency or intensity of coastal storms; changes in storm surge; ocean acidification; changes in salinity

***Time*** is another critical dimension to consider in relation to the above-mentioned aspects of climate change across both land and sea. InVEST models are scenario-based and not dynamic, and so scenarios will need to be defined for a particular point in time, with matching climate-related inputs. To investigate climate-related changes over time, a series of scenarios would need to be created and each assessed with a separate model run.

In addition to changes in climate over time, these scenarios can reflect ***biophysical and socio-economic changes in response to climate change*** – shifts in vegetation or changes in farming practices (crop type, irrigation amount and source), for example – as well as other drivers. The same is true for exploration of the role of uncertainty in climate change projections. To address uncertainty, InVEST and RIOS can be run across a range of scenarios representing the variation in predicted climate. (More details on addressing uncertainty will be available in NatCap guidance currently in the works.)

## Common model inputs that may be influenced by climate change

***Land use land cover map (common to freshwater and terrestrial models, coastal blue carbon and RIOS)***: Depending on the climate change scenario and timeframe under consideration, natural ecosystems may shift in location in response to climate change. Changes in crop suitability may also lead to changes in which crops are produced on the landscape and where. If expected changes are known, they can be reflected in land use land cover map inputs. For coastal areas, sea-level rise may inundate certain areas, and, in combination with climate change, lead to shifts in location of natural ecosystems (e.g., wetland migration). Several approaches can be used to model vegetation migration. One example is the SLAM (Sea Level Affecting Marshes) model for migration of marshes. See Guannel et al. (2014) as well as the case example in the “Coastal blue Carbon” chapter of the InVEST User’s Guide (Sharp et al. 2015) for examples.

***Habitat map (input to several marine models)*:** The distribution and abundance of coastal and marine ecosystems may change in response to changing sea level, temperature and other factors associated with climate change. If expected changes are known, they can be reflected in habitat map inputs. Climate envelope modeling and dynamics vegetation modeling are two frequently used method for projecting shifts in vegetation under climate change. See Shaw et al. 2011 for an example of the use of a dynamic vegetation model.

## Model-specific inputs that may be influenced by climate change

***Annual Water Yield: Reservoir Hydropower Production***

- *Precipitation*: maps of projected average annual precipitation, often available directly from climate change downscaling exercises, can be included
- *Average annual reference evapotranspiration*: sensitive to changes in temperature, humidity and wind. When projected evapotranspiration under climate change is not directly available, it can be estimated from projected temperature. See InVEST User's Guide (Sharp et al. 2015) for methods and associated references.
- *Z parameter*: primarily affected by the number of rain events per year. If fewer or more rain events are expected, the Z parameter can be decreased or increased slightly (following the guidance in Appendix B of the InVEST User’s Guide). If this is unknown, it is reasonable to hold the Z parameter constant.

***Sediment Delivery Ratio (SDR) model***

- *Rainfall erosivity index*: a measure of the kinetic energy of rainfall that can dislodge soil particles. This input depends on the intensity and duration of rainfall events, and may change with climate change. A future climate erosivity layer may have been developed by other researchers for particular regions (e.g., in the US (Nearing 2001); or in China (Zhang et al. 2010)). See the InVEST User’s Guide (Sharp et al. 2015) for references for calculating rainfall erosivity from precipitation data.

***Nutrient Retention: Water Purification [soon to be replaced with NDR model below]***

- *Precipitation*: maps of projected average annual precipitation, often available directly from climate change downscaling exercises, can be included
- *Average annual reference evapotranspiration*: sensitive to changes in temperature, humidity and wind. When projected evapotranspiration under climate change is not directly available, it can be estimated from projected temperature and precipitation. See the InVEST User's Guide (Sharp et al. 2015) for methods and associated references.
- *Z parameter*: primarily affected by the number of rain events per year. If fewer or more rain events are expected, the Z parameter can be decreased or increased slightly (following the guidance in Appendix B of the InVEST User’s Guide). If this is unknown, it is reasonable to hold the Z parameter constant.

***Nutrient Delivery Ratio (NDR) model [currently in beta version]***

- *Nutrient loading and retention coefficients*: the amount of nutrient exported and retained by a given LULC may change with climate. In particular, more intense precipitation events may result in higher nutrient loading. No generic guidance on incorporating climate change scenarios into these factors is available yet, but it will be developed as the model moves to a release version (which includes a precipitation input)

***Carbon Storage and Sequestration: Climate Regulation***

- *Carbon pools*: Carbon pools may be affected by changes in precipitation, temperature and $CO_2$ concentration with climate change. For example, increases in temperature may increase the decomposition rate of soil organic matter and thereby reduce soil carbon. How carbon pools may change under climate change scenarios can be estimated from literature values or other models. To represent a future climate change scenario with carbon pool values that different from a current/present scenario, the InVEST carbon model will need to be run twice, using the "current LULC" input each time, rather than using the "future LULC" input. Alternately, separate LULC classes can be defined for vegetation types under present and future conditions.

***Pollinator Abundance: Crop Pollination***

Changes in temperature and other aspects of climate change can lead to shifts in flowering time (and therefore flower resource availability) and in pollinator activity, potentially resulting in a mismatch and reduced pollination services. If information on these shifts is available from field work or existing literature, they can be accounted for in the following model parameters:

- *Flowering season by LULC type:* the timing, duration and abundance of flowering by LULC are reflected in the indices of relative flowering abundance within the land cover attribute table
- *Pollinator flight season (or activity by floral season):* the timing of pollinator activity is indicated within the table of pollinator species or guilds input.

***Crop Production***

Crop production may be affected by changes in climate, including levels and patterns of temperature and precipitation. The InVEST crop production model does not currently provide a direct way to incorporate climate change scenarios, though it may be possible to adapt the model's underlying equations to predict crop production under climate change. For more information on this possibility, please contact model lead Becky Chaplin-Kramer (bchaplin@stanford.edu).

***Visitation: Recreation and Tourism***

The recreation and tourism model does not have a prescribed set of inputs, but instead relies on users to provide any number of *predictor variables* likely to explain variation in visitation rates. There are many ways that climate change can be incorporated into predictor variables and future scenarios, and the most meaningful approach will depend on the kinds of recreation or tourism being considered, and the local manifestations of climate change. For example, changes in weather might alter the number days with snow and affect visitation in areas with snow-reliant recreation (e.g., skiing, snowshoeing). For river-based recreation, levels of flow are likely to be important and may change with climate change. Recreation in coastal areas might be related to the available area of sandy beaches, which could decline with rising sea levels.

***Habitat Risk Assessment***

- *Stressor layer and associated stressor criteria:* Climate factors can be included as one of the stressors in the habitat risk assessment model. The model assesses risk based on both exposure of the habitat to different stressors and habitat specific consequences. The criteria for habitat-specific consequences, such as change in structure or change area, can be scored based on the literature and should match the climate factor or stressor of interest (i.e., coral may be more sensitive to warming temperatures than mangroves). The spatial extent of the stressor may also change with climate change. For example, the area of ocean with a sea surface temperature (SST) above a certain degree could be greater under future scenarios of climate change; however, the resolution of such change could be on a much larger scale then the area of interest. Thus, the model may not be that useful for capturing spatial variation within a specific scenario but could still be used to assess the influence of climate between scenarios. For example, in the current scenario, SST may not be a stressor, but in future scenarios once it warmed above a certain degree that posed stressor to a particular habitat, SST would become a stressor. One other limitation of this model is that it does not include functionality to assess adaptation. Thus, the model cannot be used to say where habitat will be in the future or to explore migration; it can only be used to look at risk of degradation due to additional stress of climate.

***Coastal Blue Carbon***

- *Carbon accumulation rates*: Carbon pools and accumulation rates by coastal and marine vegetation (e.g., sea grasses, mangroves, marshes) may be affected by several factors associated with climate change and rising seas, including changes in temperature, more intense storms and degree of inundation. When carbon accumulation rates differ within a vegetation type over time, this can be represented by assigning different land use/land cover classes to that vegetation at different snapshots in time (e.g., mangroves in year 2000, mangroves in year 2025, etc.) and varying carbon accumulation rates between these classes accordingly to reflect differences in ecosystem condition related to climate change. These values can be estimated from the literature and field observations.

***Coastal Vulnerability Model***

- *Sea Level Rise:* Appendix B of the User's Guide (Sharp et al. 2015) provides details on how to create this. Sea-level rise scenario information from the IPCC report, for example, could be coupled with long term historical tide gauge data to capture spatial variation among sites within current and future sea-level rise scenarios. See Arkema et al. (2013) for an example.
- *Climatic forcing grid:* Represents wind and wave values, which may change with climate change. Appendix B of the User's Guide (Sharp et al. 2015) provides details on how to create this.
- *Habitat Ranks:* Habitat such as marsh or coral reef may or may not keep up with sea-level rise. For example, a barrier reef may be assigned a rank of 1 in the present scenario but if it cannot keep up with sea-level rise, its ability to protect the shoreline will decrease as it gets deeper underwater. If the user wants to reflect this in the model, they could reduce the protective rank of the reef in the future scenario.

***Wave Attenuation and Erosion Reduction: Coastal Protection***

- *Land point & polygon*: Sea-level rise may change the location and the shape of the shoreline, which can be reflected in this input.
- *Bathymetry grid*: depth will change based on the degree of sea level rise and can be reflected in this input
- *Wave height and period*: these may change with climate change and these values can be adjusted based on the literature, such as IPCC regional scenarios
- *Storm characteristics:* An increase in storm intensity could be reflected in the model as changes in wind speed, wave height and period, storm surge elevation and storm duration, as well as return period of the storm (if running valuation)

***Marine Water Quality***

The *tidal dispersion coefficients* and *advection vectors* may change with climate change as a result of sea level rise and especially changing ocean currents. Adjusting these parameters likely will require consulting an oceanographer.

***Wave Energy Production***

Increases in wave height and slope associated with climate change may increase available wave energy resources. Incorporating these changes into the InVEST wave energy production model would require recreating the *wave base data* input, which is currently provided as a default input for current conditions. With the current model, this will be technically challenging. We plan to add a module to facilitate inclusion of custom data in a future version of the model.

***Offshore Wind Energy Production***

- *Global wind energy parameters:* Increasing temperatures associated with climate change may in some places reduce the icing of turbines, leading to increased turbine available for energy production. This can be accounted for by adjusting the "*loss_parameter*" in this input table. However, modern wind turbine availability is generally already quite high (e.g., 98%), so the effects of any reduced icing are likely to be small.
- *Wind data points:* Wind data for current conditions is provided as a default, without an easy way for users to input their own data. To account for any changes in wind speed that might occur with climate change, the default data would need to be adjusted or replaced, which will be technically challenging.

***Marine Finfish Aquacultural Production***

- *Daily water temperature at farm*: Climate change may lead to increases surface water temperatures, which affect fish growth rates. Climate change scenarios can be reflected in this input table.

***Fisheries***

- *Population parameters*: Population parameters such as survival and fecundity rates may be affected by various aspects of climate change, including changes in temperature and pH. For example, Toft et al. (2013) assessed climate change scenarios on Dungeness crab production by adjusting survival rates based on published experimental studies.

- *Recruitment parameters*: Population productivity or carrying capacity may be affected by changes in temperature. A literature review could be used to determine how to adjust these parameters to reflect climate change scenarios.
- *Habitat changes*: Climate-driven changes in the availability of fish habitat can be reflected through the Habitat Scenario Tool, which adjusts fish survival rates based on changes in habitat availability. See Guannel et al. (2014) for an example linking shrimp survival and production to changes in available habitat under scenarios of sea level rise.

***RIOS (Resource Investment Optimization System)***

- *Rainfall erosivity index (erosion control and phosphorus retention objectives):* a measure of the kinetic energy of rainfall that can dislodge soil particles. This inputs depends on the intensity and duration of rainfall events, and may change with climate change. Future climate erosivity layers may have been developed by other researchers for particular regions (e.g., in the US (Nearing 2001) or in China (Zhang et al. 2010)).See the InVEST User's Guide for references for calculating rainfall erosivity from precipitation data.
- *Mean rainfall of wettest month (flood risk mitigation objective):* maps of projected monthly precipitation during the wet season can be calculated from downscaled climate change model results.
- *Precipitation (groundwater recharge, dry season baseflow objectives):* maps of projected average annual precipitation, often available directly from climate change downscaling exercises, can be included
- *Average annual actual evapotranspiration (groundwater recharge, dry season baseflow objectives):* sensitive to changes in temperature, humidity and wind. When projected evapotranspiration under climate change is not directly available, it can be estimated from projected temperature, and vegetation cover, for example using the InVEST annual water yield model with future climate and land cover as inputs.
- *Beneficiaries (all objectives):* depending on the climate scenario and time frame chosen, users may wish to consider a change in the location or number of beneficiaries for the ecosystem services of interest.  For example, if there is a shift in crop suitability areas or practices (e.g. expanding irrigation) then the beneficiaries for dry season baseflow may change location or increase.  These changes could be reflected in the beneficiaries inputs for the relevant objectives.
- *Activity feasibility (land use classification table) and Activity preferences (prefer/prevent areas):* Users should consider carefully whether activities that are being considered for current conditions are applicable under potential future climate conditions.  For example, *reforestation* may be a suitable activity anywhere on the current landscape, but with climate change, local climate conditions may not any longer be suitable to support forested ecosystems in some areas.  In that case users can change the land use classification table or specify activity prefer/prevent areas to reflect changing suitability for activities in different areas.  These decisions should be based on projected future conditions, best professional judgement and/or results from land change modeling. See Vogl et al. (2015) for an example of incorporating changes in activity feasibility as a result of climate change, through changes in agricultural suitability.

- Additional notes:
    - In general, because the RIOS model creates one recommended portfolio of activities for each set of inputs, users can compare results based on current and future conditions to see how the suggested activities differ. A more advanced analysis of portfolio robustness to both current and future conditions can be performed by batch running RIOS while changing inputs within probable ranges, then computing metrics of sensitivity and robustness. An example of a similar sensitivity analysis for RIOS and recommended metrics are given in Bryant et al. (2015).
    - Note that because RIOS ranks activity areas based on their suitability relative to the rest of the input area, any homogeneous change in inputs (i.e. where the pixel ranking doesn't change) will have no effect on outputs. For a small study area (small in relation to the resolution of global climate change model outputs) it may be that there is very little difference apparent between activity portfolios recommended for current and future conditions. This can occur if only climate-related inputs are changed (such as precipitation or erosivity) – as opposed to also changing land cover or activity suitability assumptions – and particularly if the change from current to future climate is relatively uniform across the landscape.

## Useful global climate datasets

WorldClim downscaled IPCC5 climate projections: http://www.worldclim.org/CMIP5

NASA Earth Exchange Global Downscaled Daily Downscaled Projections (min and max temperature and precipitation at 25km resolution): https://cds.nccs.nasa.gov/nex-gddp/

## References

*(* indicates examples of incorporating climate change scenarios into ecosystem service assessments using InVEST or RIOS):*

*Arkema, K. K., G. Guannel, G. Verutes, S. A. Wood, A. Guerry, M. Ruckelshaus, P. Kareiva, M. Lacayo, and J. M. Silver. 2013. Coastal habitats shield people and property from sea-level rise and storms. *Nature Climate Change* 3(10): 913-918. doi: 10.1038/nclimate1944

Bryant, B. P., S. Wolny & A. L. Vogl. 2015. *Understanding RIOS sensitivities, strengths, and weaknesses: a demonstration in the Coyote Creek watershed.* Natural Capital Project. Available online at: https://www.dropbox.com/s/r4fzu9hvjzt14as/RIOS%20SA%20guidance_v3_FINAL_2015-08-14_clean.pdf?dl=0

*Guannel, G., A. Guerry, J. Brenner, J. Faries, M. Thompson, J. Silver, R. Griffin, J. Proft, M. Carey, J. Toft & G. Verutes. 2014. *Changes in the Delivery of Ecosystem Services in Galveston Bay, TX, under a Sea-Level Rise Scenario*. Available online at: http://www.naturalcapitalproject.org/pubs/Ecosystem_Service_Valuation_Galveston_Bay_Sea_Level_Rise_Scenario.pdf

Nearing, M.A. 2001. Potential changes in rainfall erosivity in the U.S. with climate change during the 21st century. *Journal of Soil and Water Conservation*. 56:229–232.

*Rosenthal, A., K. Arkema, G. Verutes, N. Bood, D. Cantor, M. Fish, R. Griffin & M. Panuncio. 2013. *Identification and Valuation of Adaptation Options in Coastal-Marine Ecosystems: Test case from Placencia, Belize*. Available online at:

http://community.eldis.org/.59c095ef/Identification%20and%20Valuation%20of%20Adaptation%20Options%20in%20Coastal%20Belize%20FINAL.pdf

Sharp, R. et al. 2015. *InVEST User's Guide*. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy and World Wildlife Fund. Available online at: http://data.naturalcapitalproject.org/nightly-build/release_default/release_default/documentation/

Shaw, M. R., L. Pendleton, D. R. Cameron, B. Morris, D. Bachelet, K. Klausmeyer, J. MacKenzie, D. R. Conklin, G. N. Bratman, J. Lenihan, E. Haunreiter, C. Daly & P R. Roehrdanz. 2011. The impact of climate change on California's ecosystem services. *Climatic Change*. 109:S465-S484. doi: 10.1007/s10584-011-0313-4

Toft, J. E., J. L. Burke, M. P. Carey, C. K. Kim, M. Marsik, D. A. Sutherland, K. K. Arkema, A. D. Guerry, P. S. Levin, T. J. Minello, M. Plummer, M. H. Ruckelshaus & H. M. Townsend. 2013. From mountains to sound: modelling the sensitivity of Dungeness crab and Pacific oyster to land–sea interactions in Hood Canal, WA. *ICES Journal of Marine Science.* doi: 10.1093/icesjms/fst072

*Vogl, A. L., S. Wolny, A. Calvache, H. Tallis & S. Benitez. 2015. *Science-based investment targeting for the Water for Life and Sustainability Fund, Colombia*. The Natural Capital Project. Available online at: http://www.naturalcapitalproject.org/wp-content/uploads/2015/11/WaterFund_Case_Study_Cauca_22Sep2015_eng.pdf

Zhang, Y.-G., M. A. Nearing, X.-C. Zhang, Y. Xie & H. Wei. 2010. Projected rainfall erosivity changes under climate change from multimodel and multiscenario projections in Northeast China. *Journal of Hydrology*. 384: 97–106.