ccviR: an R package and Shiny app to implement the NatureServe Climate Change Vulnerability Index

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Summary

Background

Climate change vulnerability assessments (CCVAs) are tools increasingly adopted to rank species' vulnerability to the threat of climate change (Pacifici et al., 2015). Common CCVA approaches include trait-based, correlative models (e.g. species distribution models), mechanistic models (e.g. mechanistic niche models), or a combination of these approaches (Foden et al., 2019; Pacifici et al., 2015). CCVAs can be used to inform extinction risk assessments by identifying the mechanisms and magnitude of impacts (Foden et al., 2019). One popular trait-based CCVA tool is the NatureServe Climate Change Vulnerability Index (CCVI), which is a rapid assessment tool that ranks species' vulnerability to climate change and highlights factors contributing to increased vulnerability(Young et al., 2016; Young, Dubois, & Rowland, 2015). Outputs of the NatureServe CCVI can inform conservation decisions and identify actions to increase species' resilience to climate change.
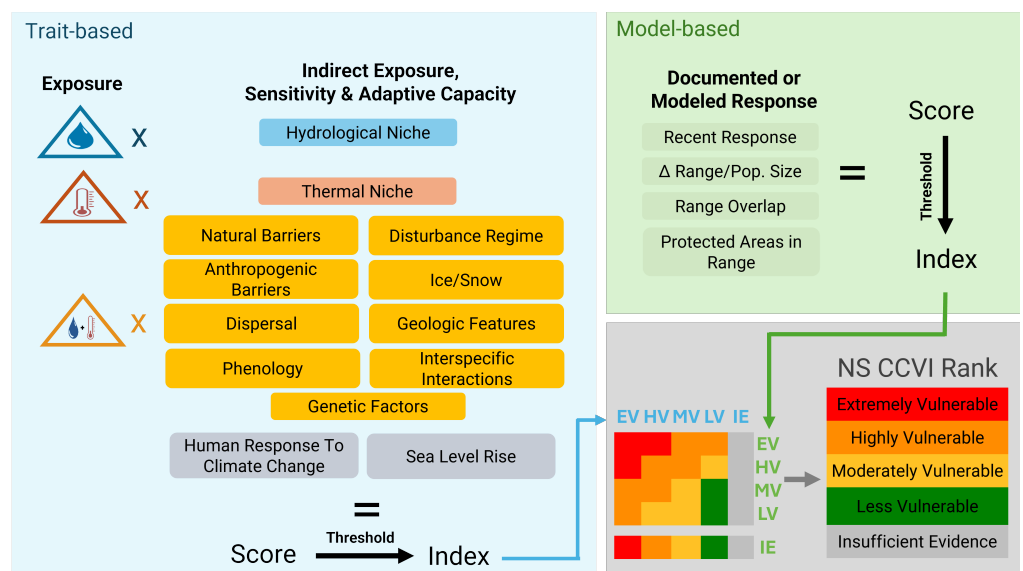

Figure 1: Algorithm for calculating the NatureServe Climate Change Vulnerability Index.

The NatureServe CCVI combines several components that contribute to a species' vulnerability to climate change, including exposure to changes in temperature and moisture (Section A), indirect exposure to other changes brought on by climate change (e.g. sea level rise; Section B), and traits related to species' sensitivity or ability to adapt to climate change (Section C;

Figure 1). It also optionally incorporates the results of documented or modeled responses to climate change (Section D; Young et al., 2012, 2016). The resulting CCVI ranks include: 'Less Vulnerable', 'Moderately Vulnerable', 'Highly Vulnerable', 'Extremely Vulnerable' or 'Insufficient Evidence'. Exposure is assessed by determining the proportion of the species' range that falls into six classes of temperature and moisture change, which is used to assign an exposure multiplier. Sections B, C and optionally D are each scored on a scale from 'neutral' (score: 0) to 'greatly increases vulnerability' (score: 3). The indirect exposure, sensitivity and adaptive capacity scores are multiplied by the exposure multiplier and summed. The final CCVI value is a result of applying thresholds to the total scores and balancing the sensitivity and adaptive capacity rank with the documented or modeled response rank (Figure 1).

Functionality

The NatureServe CCVI tool is an Excel workbook that users complete using available scientific information, expert opinion, and spatial analyses. While the tool is straightforward to use, it requires users to possess technical Geographical Information System (GIS) skills and access to software (often proprietary) to perform the spatial analyses. This challenges the implementation of reproducible analyses, which are increasingly required for credible scientific processes (Munafò et al., 2017). In addition, the Excel-based version requires repeated assessments to assess uncertainty associated with choice of Global Climate Models or emission scenarios.

To improve accessibility and reproducibility of the NatureServe CCVI we developed ccviR, an R package and Shiny app that implements the original CCVI in an easy to use Graphical User Interface (GUI). ccviR applies the original scoring algorithm to assess vulnerability and includes the original Monte Carlo uncertainty analysis. A major advance of ccviR is the functionality to perform spatial analyses internally, using R, such that advanced GIS skills and costly software are not required. Users are only required to specify the locations of spatial data files on their computer, using the Shiny app or R code, and ccviR automates all spatial analyses. Examples of these automated spatial processes include overlays of the species' range with exposure categories, historical climate regime, and modeled changes in the species' range. The ccviR Shiny app presents the results of the spatial analyses using interactive maps, that allow for user-directed validation of the spatial analyses and opportunities to modify the resulting factor scores, if desired. Additional interactive plots allow users to explore what factors are driving the vulnerability of a species (Figure 2). Another significant addition is a second Shiny app that allows users to classify independently-supplied climate data sets into the exposure categories used by the index based on the median and half the interquartile range. This makes the methods used to determine exposure classes explicit and repeatable for different climate data sets or different regions. Finally, ccviR includes functionality to assess the consequences of uncertainty associated with choice of emission scenarios and/or global circulation models on CCVI outcomes.

The ccviR Shiny app can be launched from an R session with one line of code and runs locally, allowing easy access to files. While using the app, assessments can be saved to a csv file at any point, then the csv file can be used to restart the app and continue the assessment. The human readable csv format ensures that comments and assessment values can be used independent of the ccviR package which facilitates transparent and reproducible assessments. These csv files can also be used to compile data from multiple assessments for further analysis and synthesis. ccviR facilitates communication of scientific outcomes by including functionality to generate a pdf report summarizing the assessment.
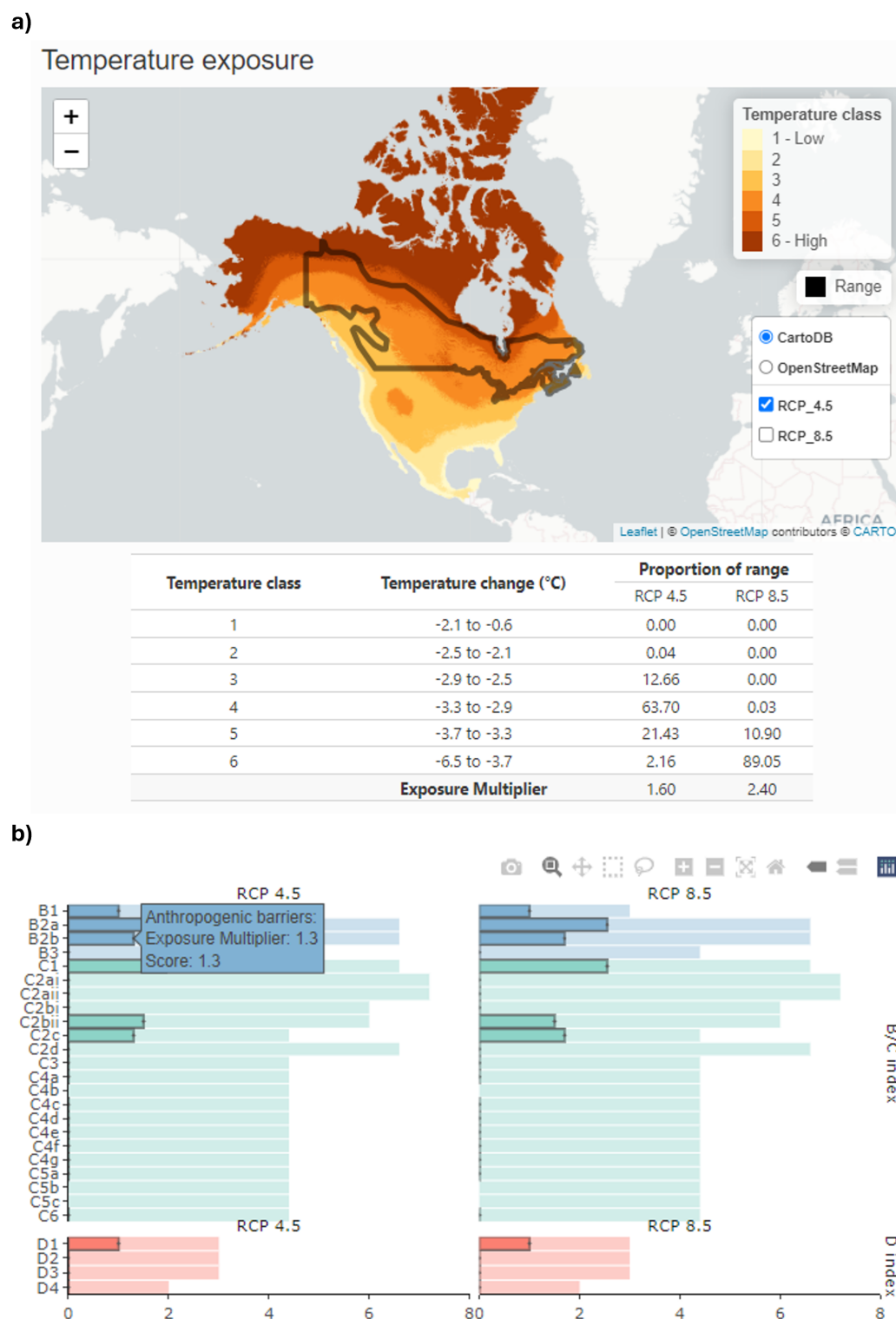
Figure 2: Interactive visualizations in the ccviR app allow validation and interpretation of results for a) the calculation of the temperature exposure multiplier and b) the scores for each vulnerability factor used to calculate the index.

Example

The code below will open the app in your default browser with an example data set available.

```
library(ccviR)
run_ccvi_app("demo")
```

While the following will open the app with the current working directory as the default data location.

```
run_ccvi_app()
```

Statement of need

The ccviR R package and Shiny app facilitates a seamless, accessible, and reproducible version of the NatureServe CCVI, that ensures an enhanced and intuitive user experience. The inclusion of the spatial analysis components within the package removes the need for additional GIS software, reduces the amount of technical skills needed to perform CCVI assessments and allows conservation practitioners to focus on their areas of expertise. Simultaneously, ccviR ensures that analyses are consistent and reproducible across species. While the Shiny app increases user friendliness for a wide audience, the ccviR package allows more proficient R users to customize their analysis workflow and more easily assess many species or perform sensitivity analyses to assess the consequences of multiple forms of uncertainty. The R package framework ensures the CCVI is open with code and documentation available as well as unit tests to verify the functionality of the tool. The inclusion of a Shiny app to allow users to create their own custom climate exposure data in ccviR extends the potential uses of the index to a greater geographic area and allows users to follow best practices of incorporating multiple future climate models and emission scenarios in their assessments.

Acknowledgements

The authors acknowledge Adriana Caswell for assistance with development and testing of this package and Bruce Young for help with understanding the NatureServe CCVI algorithm.

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