Explanation and guidance for a decision-support tool to help manage post-fire Black-backed Woodpecker habitat

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Rationale

The stochastic and unpredictable nature of wildfire necessitates rapid assessment of post-fire forest resources and wildlife populations in order to make timely decisions about post-fire forest management. Predicting the abundance of uncommon, elusive, and wide-ranging species like Black-backed Woodpeckers poses particular problems that call for the combination of multiple and independent sources of data (Gopalaswamy et al. 2012). Black-backed Woodpeckers are imperfectly detected (elusive) and patchily distributed across a landscape, limiting the ability to estimate abundance independent of occupancy (i.e., the probability of being present at a point). Nevertheless, the local abundance of Black-backed Woodpeckers may be strongly influenced by habitat quality and resource availability, particularly the abundance of fire-killed snags preferred for nesting and foraging. Previously, we have developed a method for predicting Black-backed Woodpecker pair density that combines model-based estimates of occupancy with expected density given occupancy (Tingley et al. 2014a, Tingley et al. in press). This Black-backed Woodpecker abundance (BWA) model can be conceptualized as fully packing a landscape with home ranges based on habitat quality, and then subtracting home ranges based on a probabilistic process that accounts for the fact that heterogeneous landscapes are rarely occupied at maximum density (e.g., due to elevation, latitude, etc.). Here, our aim is to clearly describe the implementation of the tool and recommend how to interpret its output, in order to assist managers in making forest management decisions that account for the expected effects on Black-backed Woodpeckers.

Model Summary

Although a full description of the BWA model, its theoretical underpinnings, and its statistical derivation are provided in full detail elsewhere (Tingley et al. 2014a, Tingley et al. in press), we provide below a general description of the model.

The purpose of the BWA model is to predict the true abundance or density of Black-backed Woodpeckers in recent post-fire landscapes. The BWA model only requires landscape-level environmental information as inputs, so targeted surveys for Black-backed Woodpeckers are not required by the model to predict abundance. Indeed, all input variables are remotely-sensed environmental characteristics that are available freely and widely for California (see section below for more information on input variables). The minimal required information on forest fire characteristics are commonly assessed for all fires on public lands in California and are made publically available within a few months following the end of the fire. Consequently, the BWA model can be fully implemented and abundance estimates can be produced without on-the-ground visits to post-fire landscapes and within 2-3 months following a fire.

The BWA model takes fine-scale environmental variables covering the entire footprint of a fire and converts them to a predicted Black-backed Woodpecker abundance surface at an approximate resolution of 30x30-m. Our code (see section below) for the BWA model provides one of two output options. The first option is a Geographic Information System (GIS) map of the best estimate of woodpecker density for each 30x30 map pixel within the fire perimeter. The second option is the best estimate plus 95% credible interval for the total number of Black-backed Woodpecker pairs within a pre-defined area, such as the entire fire perimeter.

The BWA model itself is the direct product of three component models. The first component, an occupancy model, estimates the probability of the true presence (or occupancy) of a species at a location, unbiased by false absences. Following the published framework of Saracco et al. (2011), we have developed an occupancy model that predicts the probabilistic occurrence of Black-backed Woodpeckers as a function of a variety of environmental covariates. In the BWA model, the occupancy component indicates the general suitability of a post-fire landscape for Black-backed Woodpecker occupancy. In order to calculate abundance, the occupancy component is multiplied by a second component, which predicts the density of Black-backed Woodpecker territories in occupied habitat. This second component of the BWA model is derived from work examining the variation of home-range sizes of Black-backed Woodpeckers (Tingley et al. 2014b), which determined that home-range size scales exponentially with the basal area of snags within occupied territories. Black-backed Woodpeckers occupying territories with greater densities of snags have smaller home ranges. The final component of the BWA model predicts the snag basal area expected in a pixel based on remotely-sensed pre-fire and post-fire environmental conditions. This final component is necessary in order to implement the home-range size model, which requires snag basal area as an input.

Within the BWA model code, all three component models are combined. The user need only load input environmental data, implement the BWA model, and wait for output.

Code

All code necessary to implement the BWA model is provided in our Github repository: https://github.com/mtingley/BBWO_abundance. Github is a web-based repository that hosts data, source code (in many programming languages), output, instructions, and metadata. All uploads to Github utilize Git, which is a distributed revision control system. Thus, code and other files hosted on Github are dynamic, "living" files that both show archival, "fixed" versions of code and associated files, and also dynamically allow modifications to be made and subsequently tracked. If you want to learn more about Github, there are many online resources with several good introductions for beginners.

Utilizing the BWA model and implementing the code requires almost no interaction with Github. Just follow the link to the github repository (above), and click the link on the right labeled "Download ZIP." The entire repository will be downloaded to your chosen directory and the files can be opened and examined locally.

The BWA repository itself consists of several directories ("GIS_Reading", "Occupancy_model", "Snag_model", "Telem_model") that contain some of the inner machinery of the model but do not need to be opened. The directory "Output" is where objects will be created by default in the course of implementing the model. The main directory itself contains three files that will be of use. The file "readme.txt" provides instructions that complement the ones you are reading. The files "Area_abudance_predict.R" and "Fire_density_predict.R" are code scripts in the R language that will be needed to implement the BWA model.

Input data

Before implementation, the BWA model requires several types of environmental that data need to be prepared in a standardized format. For fires on public lands in California, these data layers are generally freely and readily available. Example data files for the Reading fire are provided on the Github repository. For a new fire prediction, the required data inputs are as follows:

1. *Elevation* (raster): In meters, derived from a fine-scale Digital Elevation Model (DEM). DEMs deriving from the Shuttle Radar Topography Mission (SRTM) are available at approximately 30-m resolution within the continental United States and can be downloaded from multiple sources, including the USGS Earth Explorer.

2. *Pre-fire canopy cover* (raster): An integer from 0 to 100, representing the percent canopy cover of a forest section prior to fire. Can be derived from the National Land Cover Database (NLCD), the most recent version of which is from 2011.

3. *Tree size class* (raster): An integer of 0-6, indicating the dominant WHR tree size class within the stand (6 being the largest class). Provided in the California Fire Response and Assessment Program (FRAP) vegetation database. The most recent database is "FVEG15_1" and size class is under the data column "WHRSIZE".

4. *WHR forest class* (raster): An integer from 1 to infinite, representing the dominant WHR forest type within the stand. WHR forest types can be derived from the FRAP vegetation database, as above, under the data column "WHRTYPE", which provides 3-character strings that identify each forest type. These strings should be converted to integers, and a crosswalk document that matches each unique integer with the 3-character forest type should stored separately (see next item).

5. *WHR crosswalk* (comma-separated value data file): A simple data file that includes at least one column that lists each integer present in the WHR forest class raster (item #4 above; labeled "ID" in example file on Github), and one column that translates the numerical ID to the 3-character WHR type. Such a crosswalk can easily be created by viewing the data table associated with a raster in ArcGIS.

6. *Burn severity* (raster): An integer from 0 to 100, representing the percent change in canopy cover from pre-fire to post-fire. Such a layer is typically produced as part of the Rapid Assessment of Vegetation Conditions after Wildfire (RAVG) program on National Forest lands. Fires occurring on National Forest lands in Region 5 can be searched online and RAVG data layers can be downloaded as a single .ZIP file. Users should read the associated metadata for each fire, but percent change in canopy cover is typically a file that includes "_cc" in the name.

7. *Latitude* (raster): A decimal, from -90 to +90, representing the latitude on the Earth's surface, in decimal degrees. Can be easily extracted from any gridded and georeferenced spatial surface, such as elevation (item #1 above).

8. *Fire perimeter* (or *analysis boundary*, a vector file with 1 feature): A single polygon that outlines the area of analysis. The area of analysis is the spatial extent in which the BWA model will be implemented. If the expected number of Black-backed Woodpecker pairs is desired as output, the analysis boundary defines the area in which expected densities are summed. As default, this area is the fire perimeter (as in the example for Reading). Fire perimeter polygons (as ESRI Shapefiles, .shp) are included with RAVG downloads (see item #6, above).

In addition to downloading and organizing input data items 1-8, additional pre-processing of data inputs will likely be necessary prior to model code implementation. The three most likely types of pre-processing are: (1) conversion to appropriate file format, such as conversion of GIS data from vector class to raster class; (2) converting all raster files to the same geographic coordinate system (and/or projection); (3) converting all raster files to the same spatial resolution; and (4) making sure all input files are in the correct numerical format as expected by the BWA model code (see specifications above). The above descriptions indicate the required data class for each input (e.g., raster or vector). Many data downloaded from online sources (e.g., items #3 and 4) will be stored in vector shapefiles, but need to be converted to gridded raster data for analysis. This can be done either in R or a GIS program such as ArcGIS or QGIS, but should be done with care and with the consultation of an experienced geospatial analyst, when appropriate. Similar care should be heeded for conversion of resolutions and coordinate systems. For analysis, the BWA model will take input data of any resolution and coordinate system, as long as all input files match. However, based on the scale upon which the model has been parameterized and tested, we highly recommend a resolution of 30x30 meters (approximately 1 arcsecond), which is helpfully the resolution of both DEM data from SRTM3 as well as burn severity data produced by RAVG. The choice of file storage structure also lies with the user. For ease of use and file size reasons, the BWA code we provide outputs rasters as GeoTIFFs. Finally, it is critical that the values present within input files match the numerical characteristics described above. For example, percentages (e.g., % pre-fire canopy cover) should be stored as 0-100 integers, not 0-1 decimals. If in doubt, double-check input files versus the example inputs provided for the Reading fire at the GitHub site. Numerical mismatch may not cause errors when implementing the BWA model code, but will result in "plausible" yet wildly incorrect output values.

Implementation

Once input data files have been acquired and pre-processed, the BWA model can be implemented. Either of the two model code files should be opened, "Area_abundance_predict.R" or "Fire_density_predict.R," depending on whether the total number of Black-backed Woodpecker pairs expected within a set area, or a continuous surface of Black-backed Woodpecker density is desired for the model output, respectively. Actual implementation is identical for either script file, and the files only differ in their output and calculations.
R script files can be opened up directly within the program R or through a 3rd-party interface, such as RStudio. Instructions for installing and using R and RStudio are widely available online. Once a script has been opened, sections of code can be selected and run. Depending on your prior use of R, several add-on packages for R may need to be installed, including raster, rgdal, and R2jags, and their associated dependencies. The package rgdal connects to the geospatial data abstraction library (GDAL), which may need to be installed, particularly for Mac users.
Once libraries and downloaded data files have been successfully loaded into R (script lines 1-31), the code will need slight modifications in order to load in input data to apply the BWA model to a new fire. The script available on Github defaults to using the input data for the Reading fire, but lines 38-46 will need to be edited in order to point R to your local directory holding each of the input files.

If input files are loaded in correctly, then the rest of each script should execute without producing errors.

Both BWA scripts involve sampling randomly from Bayesian posterior distributions of modeled parameters. The number of random samples is an arbitrarily large number chosen by the user. In both cases, the default is 5,000 random samples (line 103 in "Fire_density_predict.R" and line 99 in "Area_abundance_predict.R"). Although we warn that setting this number very low (e.g., <500) will likely result in biased predictions with high uncertainty, the calculation time can be sped up considerably by reducing this number below 5,000. We recommend a posterior sample of 5,000, however, if time allows. There should be no need for samples greater than 5,000.
After script execution, outputted estimates will be saved within the subdirectory called "Output" by default. Outputted objects will include GeoTIFF spatial layers (for "Fire_density_predict.R") and a posterior distribution of the total number of expected pairs (for "Area_abundance_predict.R"). Summaries of the posterior abundance estimate are printed

directly following execution of the relevant script section (i.e., lines 164-166 of "Area_abundance_predict.R").

Recommended Usage of BWA Model outputs

Our aim in developing this model was to provide a tool to allow managers to make forest management decisions that account for the expected effects on Black-backed Woodpeckers. We are not suggesting any specific threshold of burned forest snag retention for post-fire forest management. It is up to land managers and agency decision makers to decide how much burned forest retention is appropriate in a given landscape based on project goals and management objectives.

We caution that the expected density of woodpeckers (either as a spatial map, or as a total abundance estimate) should not be misconstrued as known density, and that both maps and abundance totals should be considered with respect to modeled uncertainty (included as part of output for both scripts). While tests of the BWA model indicated that modal (i.e., our best expectation) model predictions of woodpecker density were reasonably close to reality at 4 evaluation fires (Tingley et al. in press), we acknowledge that model uncertainty may be quite high for some applications of the BWA model. Thus, we suggest that managers primarily use the density estimates to examine the relative effects of different habitat retention scenarios on Black-backed Woodpecker populations. Specific examples of how to do so are provided in Tingley et al. (2014a).

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