Guidance to tree species tables

The following guidance explains how to read and understand the complex data tables created by researchers at the U.S. Forest Service as part of a study of tree species adaptability to climate change in the LEAP region. The study provided tables with data covering the entire region and parts of the region.

There are three sections to the guidance:

- Detailed description of each column of the tables
- Additional guidance for interpreting the tables
- Suggestions for using the data to pick trees species that will be well adapted to future conditions

Note: FIA refers to the Forest Inventory and Analysis Program of the U.S. Forest Service, which tracks the distribution and abundance of trees across the nation.

Detailed variable descriptions

Following is a brief summary of each column on the species tables. Each column on the Excel spreadsheet can be sorted (click on header variable arrow) to gain maximum information extraction. General information regarding our modeling schemes can be found in Iverson et al. 2008, 2011; 2017; Matthews et al. 2011; Peters et al. 2015; Prasad et al. 2016 (see references at end). In the listing of column headers below, the **bolded** variables are visible on the spreadsheet, while the non-bolded variables are hidden, but retrievable, from the spreadsheet.

DISTRIB2 output variables

FIA: a numeric code assigned according to US Forest Service Forest Inventory and Analysis (FIA) units, indicating the species is found or is projected to have suitable habitat under some climate change scenario by 2100, within at least 1 cell[a] within in the area of interest.

Common Name: species common name used by FIA.

PC: Planting code. If the PC code is 1, 2, or 3, we suggest you consider them for planting. Those coded 0 are also to be considered for particular locations depending on local conditions. These codes are explained at the bottom of this document.

Scientific Name: species scientific name used by FIA.

ModRel: the model reliability of the species' model predicting current and future suitable habitat (High, Medium, Low), based on several statistical parameters[b]. If coded 'FIA only', the model is unacceptable for predicting into future, thus the change classes and capability classes are unknown.

%CellFIA: the percentage of cells[a] within the 1x1 degree of Lat/Lon (or other area) zone that currently have the species present according to the FIA data. It does not mean the species actually covers that amount of ground within the sample area. Also, if the 1x1 is only a partial rectangle because of coast or water, or because of the region of interest, there may be pieces without FIA plots or missing environmental predictors, therefore small fractions of the 1x1 without certain common species. Also, the region could be selecting only a small fraction of a cell with the species present.

FIAiv: the average importance value (IV) according to FIA records for the species, where it occurs, within the 10x10 and/or 20x20 km cells[a] of the area of interest. The 0-100 score is based on number of stems and basal area of tree species recorded during the most recent FIA inventory cycle (FIA data used from across the eastern US range from 2001-2016). IVs are averaged at the cell[a] level to indicate the average abundance of a species. Note that this IV is for the species only within the cells where it now occurs, not averaged over the entire region of interest.

FIAsum: the area-weighted sum of the importance value (IV) according to FIA records for the species within cells[a] within the area of interest. These values have been corrected for partial 1x1 degree zones (to 10,000 km^2), and for varying sizes north to south (curvature of earth makes zones narrower towards the poles) according their proportion of a full 1x1 degree zone at mid latitudes.

ChngCl45 or **ChngCl85**: class of potential change in habitat suitability by 2100 according to the ratios of future (2070-2099) suitable habitat for an average of 3 GCMs to current (1981-2010) modeled habitat, using either lower emissions (RCP 4.5) or higher emissions (RCP 8.5). Classes follow ratios as shown in the table below, for common species. When MODi was >0 for <10% of the cells[a] within the 1x1 degree zone, the species was categorized as 'rare' and the change classes were expanded, so that NoChange=ratio 0.6-4.0; Sm. inc.=ratio 4.0-8.0; Lg. inc.=ratio >8.0; Sm. dec.=ratio 0.2-0.6; Lg. dec.=ratio <0.2.

Class	**Criteria**	**Description**
NoChange	Ratio of 0.8 – 1.2	No Change to very little change in habitat suitability
Sm. inc.	Ratio of 1.2 – 2.0	Small increase in habitat suitability
Lg. inc.	Ratio > 2.0	Large increase in habitat suitability
Sm. dec.	Ratio of 0.5 – 0.8	Small decrease in habitat suitability
Lg. dec.	Ratio < 0.5	Large decrease in habitat suitability
Very Lg. dec.	FIAi > 0.5 and GCM45i = 0	Very large decrease in habitat suitability
Unknown	ModRel = unacceptable	Not enough information to assign a class due to very low model reliability or species is extremely rare either now or potentially in future.
New Habitat	MODi = 0 and GCM45i > 0	Species is not currently reported by FIA and has not been modeled under current conditions to have suitable habitat, but could gain suitable habitat under future climate conditions.

Adapt: Adaptability score for the species, according to a literature review of 12 disturbance and 9 biological characteristics, or modification factors (Iverson et al. 2011; Matthews et al. 2011). Scores range from 1.7 (very low adaptability to a changing climate) to 8.5 (very high adaptability), with color class breaks at 3.4 and 5.2. Thus low adaptability is 1.7-3.4, medium is 3.5-5.2, and high is >5.2.

Abund: based on FIAsum within a 1x1 degree zone, the abundance of the species based on last FIA inventory cycle, corrected for 1x1 degree zone size as described above. We realize these are subjective cutoffs, but does have merit based on multiple evaluations. Users could change cutoffs to meet their neets.

Class	**Criteria**
Abundant	FIAsum > 75
Common	5 ≤ FIAsum ≤ 75
Rare	0 < FIAsum < 5
Modeled	FIAsum = 0 and MODi > 0
Absent	FIAsum = 0 and MODi = 0

Capabil45 or **Capabil85**: the overall estimate of capability for the species to cope with the changing climate (higher emissions scenario) within the study area. Capability class is based on the Change Classes (potential changes in suitable habitat by end of century), which in turn are based on the ratio of future to current (see above) across three GCMs at RCP 4.5 or 8.5 and the Adaptability of the species to the added disturbances likely under climate change. Classes range from Very Good to Good to Fair to Poor to Very Poor to Lost (no habitat under GCM85i) to Unknown (Unknown ChngCl45/ChngCl85, see ChngCl45 description above) to New Habitat (see ChngCl45 description above) to NNIS (if the species is not native), to FIA only (if the species only is recorded in FIA inventories but not sufficient for modeling. First, the ChngCl45/ChngCl85 is considered, followed by Adapt to arrive at an initial capability. Then Abundance is used to modify classes so that if the species is Abundant, we increase capability by one class (e.g., poor to fair, or good to very good); if species is Rare, we decrease capability by one class (e.g., poor to very poor); if species is Common, there is no change in capability. The idea is that common species are more likely to find refugia into the future, and rare species are less likely. [ChCl=change class (Large Decreaser LD, Small Decreaser SM, No Change NC, Small Increaser SI, Larger Increaser LI); Adapt=Adaptability class (High H, Medium M, Low L)].

Class	**Criteria**
Very Good	ChCl=LI, Adapt=H or M; ChCl=SI, Adapt=H
Good	ChCl=LI, Adapt=L; ChCl=SI, Adapt=M; ChCl=NC, Adapt=H
Fair	ChCl=SI, Adapt=L; ChCl=NC, Adapt=M; ChCl=SD, Adapt=H; ChCl=LD, Adapt=H
Poor	ChCl=NC, Adapt=L; ChCl=SD, Adapt=M or L; ChCl=LD; Adapt=M
Very Poor	ChCl=LD; Adapt=L
Lost	Species with suitable habitat lost from the zone by 2100
New Habitat	Species with new habitat appearing in the zone by 2100
FIA only	Species with unacceptable model so that only FIA data are reported
NNIS	Non-native invasive species – only noted if FIA records them

N: the count of species considered in the study area.

SHIFT output variables

SHIFT applies to natural colonization into previously unoccupied habitats for each species. First of all, DISTRIB habitat model predicts future abundances as though there is no limit to migration. We therefore call them "habitats" instead of "distribution" or "abundances". One of the criticisms of species distribution models is that they assume no migration limit. Therefore, the role of SHIFT is to provide migration limits to DISTRIB (we call it adding a dose of reality to the predicted future habitats) - i.e., what is the likelihood that the future habitats predicted by DISTRIB will be colonized?

SHIFT calculates the colonization likelihood based on the FIA abundances and generation times of the species (among other things) to match the future predicted habitats of DISTRIB. Here is where Habitat Quality and Colonization Likelihood (HQ-CL) becomes relevant. HQ-CL represents areas that combine habitat quality with colonization likelihoods - i.e., where in the forested eastern US landscape will suitable combinations of HQ-CL be found (obviously we want highQuality-habitats and highLikelihood-colonizations - but these combinations may be limited. However, we can identify the best HQ-CL combinations available for any species and target them for management (relocation etc.) if needed since they in turn can contribute propagules to assist in further migration.

Another point is the value of SHIFT in selecting potential species for planting. Because DISTRIB delineates only suitable habitat, and there is a varying degree of reliability in those models, there are some species that predict massively from their current distribution. We believe it prudent to plant those species that are relatively closer to their locations of potential migration naturally within 100 years (e.g., 1 seed zone away). We have taken a very generous approach to selecting species, first noting those with even a fraction (>0) of probability of colonization within 100 years, then noting that it preferable to select those with at least 5% of the area with at least 2% probability of colonization. This process narrows the list, and discouraging the selection of species that are way, way out of current range limits.

%OccCol (hidden): Percent of study area that is occupied added to areas that have some chance (>0%) of getting colonized.

%2Col: Percent of study area that has at least 2% chance of getting colonized within 100 years.

%AnyCol: Percent of study area that has more than 0% chance of getting colonized.

HQCL45 or **HQCL85:** Habitat quality and colonization likelihood weighted score. This index is derived by combining the outputs of DISTRIB2 and SHIFT to get at desirable combinations of both habitat quality and colonization likelihood. The score is based on a cells' habitat quality class of low (IV=1-5), medium (IV=6-15), high (16-100) as well as colonization likelihood probability of low (1-10%), medium (11-50%), and high (51-100%). The weighted score provides more value to locations with both higher levels of suitable habitat and higher levels of colonization likelihood according to the following table:

Habitat Quality (HQ)	Colonization Likelihood (CL)	Multiplier
Low (1)	Low (1)	2
Low (1)	Medium (2)	3
Low (1)	High (3)	4
Medium (2)	Low (1)	5
High (3)	Low (1)	6
Medium (2)	Medium (2)	7
Medium (2)	High (3)	8
High (3)	Medium (2)	9
High (3)	High (3)	10

[a]The eastern US was carved into a hybrid grid of 10x10 or 20x20 km cells, based on the quantity of FIA inventory plots. In the western portion of the eastern US, the original vegetation was primarily prairie (now cropland), and forests are much less common. Therefore, these areas need larger cells in order to capture forest trends sufficiently for modeling, e.g., two or more FIA plots within a cell.

[b]Multiple factors were used to generate the ModRel classification, including the pseudo R^2 (scaled) of the Random Forest imputed model, the Fuzzy Kappa, the percent deviance explained by the top 5 variables, the stability of the top 5 variables using 30 regression tree analysis outputs, and the total sum of squares (TSS) after removing records with very high coefficient of variation. Then if score = .23-.54 (low ModRel); .55-.69 (medium ModRel); >.7 (high ModRel).

[c]General Circulation Models considered included the CCSM4 (Gent et al. 2011), GFDL CM3 (Donner et al. 2011), and HadGEM2-ES (Jones et al. 2011) models under the representative concentration pathways (RCP) (Moss et al. 2008) 4.5 and 8.5 for a historical period of 1981 – 2010 (PRISM) and modeled projections for the period 2011 – 2099. The following table presents characteristics of these scenarios (PANN=annual precipitation; Pgrow=precipitation during April-Sept; TANN=mean annual temperature; Tgrow=mean temperature April-Sept; TWIN=mean temperature Dec-Feb; TSUM=mean temperature June-August; Aridity Index=Aridity; TMIN=absolute minimum temperature; TMAX=absolute maximum temperature.

	PRISM 1981-2010	CCSM4 RCP 4.5	CCSM4 RCP 8.5	GFDL CM3 RCP 4.5	GFDL CM3 RCP 8.5	HadGEM2-ES RCP 4.5	HadGEM2-ES RCP 8.5	GCM3 RCP 4.5	GCM3 RCP 8.5
PANN, mm	1048	1114	1163	1205	1234	1122	1111	1147	1169
Pgrow, mm	509	528	520	574	585	504	458	535	521
TANN, C	12.9	15.2	17.1	16.3	18.6	16.8	19.2	16.1	18.3
Tgrow, C	21.7	24.1	26.3	26.0	28.5	25.7	28.4	25.2	27.7
TWINavg, C	-0.9	1.2	2.1	1.6	2.0	1.3	3.3	1.4	2.5
TSUMavg, C	24.8	26.7	28.1	28.1	29.7	28.0	29.9	27.6	29.2
Aridity Index	-0.2	-0.3	-0.4	-0.3	-0.4	-0.4	-0.5	-0.3	-0.4
TMIN, C	-11.2	-8.7	-6.5	-7.3	-5.7	-7.4	-4.1	-7.8	-5.4
TMAX, C	33.9	36.0	39.3	39.1	42.6	38.5	41.9	37.9	41.3

Interpretation of tables

1. **Understanding the species and numbers of species present or potentially present:** The "**N**" variable counts the rows in the table, listing species within the area of interest, and includes (1) all native species currently occuring according to FIA, (2) non-native introduced species occuring according to FIA, (3) species not identified via FIA plots but modeled to occur, and (4) species modeled to provide suitable habitat for the area by 2100. As such, extraction and counts of subsets of species within these classes can easily be done via sorting on any particular column of interest. Species can also be presented and sorted by common name, scientific name, or FIA code.
2. **Identification of ranked order of current species:** when the **FIAsum** column is sorted largest to smallest, the table lists most dominant to least dominant species, according to the FIA inventory data. It is the sum, within the area of interest, of the importance value (IV) of the species (based equally on number of stems and basal area of those stems and standardized to 0-100) for each cell multiplied by the area of each cell occupied by that species. This number has also been calibrated to a standardized 10,000 km^2 (2.47 million acres) area, the approximate area of a 1x1 degree cell, so that **FIAsum** values can be compared across areas even though those areas are unequal in area. This gives a current snapshot of the status of most of the species. However, with only 1 FIA plot per ~5000 acres, there will be occassional species missed by the plots; of course these are usually rare species. The **FIAsum** variable is also used to class the Abundance (**Abund**) into Abundant, Common, Rare, or Absent according to the cutoffs listed in the variable explanation document.
3. **Identification of species' importance where present:** FIAi provides an indication of the average importance value (IV) of a species, on a 0-100 scale, for the cells that have the species. Therefore, certain species that may be uncommon across an area but abundant in certain locations may obtain higher scores than generally common species.
4. **Identification of species' adaptabilty to cope with conditions likely under a changing climate:** The **Adapt** variable lists a score, ranging from 8.5 for red maple, the most adaptable species to 1.7 for black ash, the least adaptable species according to 21 modification factors. These scores were obtained via several literature sources, and are described in Matthews et al. 2011. It should be noted, however, that these scores were achieved via reviewing literature across the range for each species; there may be cases were these scores should be changed based on local knowledge.
5. **Idenfication of changes in suitable habitat according the the models:** the **ChngCl45** and **ChngCl85** variables provide, for RCP4.5 and RCP8.5 respectively, the potential change in suitable habitat for the species by year 2100. It is important to note that a change in suitable habitat does not mean the species importance will actually change in that area by 2100, only that the habitat is expected to increase, decrease, or not in suitability for that species over time. Trees live a long time and often (but not always) can withstand periods of stress due to climate extremes. But, as found in the western United States, a series of 'hot droughts' or climatological trends favoring certain pests can provoke huge mortality events.
6. **Identification of the capability of species with cope with the changing climate:** with the variables **Capabil45** (RCP4.5) and **Capabil85** (RCP8.5) we combine the influence of changes in suitability, adaptability, and abundance of the species within the area of interest. As such, this is

our best estimate of the species' ability to withstand the extremes and prolonged issues from climate change, *within the area of interest*. If the species is abundant in the area of interest, it has more resources to withstand disturbances and find refuge somewhere. In contrast, rarer species may have a higher probability to be pinched out under particular extreme events. We provide tables initally sorted by **Capabil45** so that species are ranked from Very Good to Lost. Following those classes on the table are species that have New Habitat projected in the area of interest based on our models, then species that only report current information (**FIA only**) because of unacceptable models, then species that are non-native invasive species (**NNIS**).

7. **Identification of species with New Habitat but also some probability of colonization within 100 years:** With **Capabil45** or **Capabil85**, or **ChngCl45** or **ChngCl85**, we provide those species identified as New Habitat. With the SHIFT analysis, we provide the percent of the area with any chance of getting colonized (**%AnyCol**), so, generously, we can say that the species has at least a small chance to naturally migrate to the New Habitat within 100 yrs. If these criteria are met, we suggest that the species has a relatively greater potential to succeed, as compared to those with 0 in **%AnyCol**, if the species were planted within the area of interest. Higher values of **%AnyCol** would also indicate a relatively higher chance to succeed. To subset these further, we suggest you especially consider those species with at least a 5% of the area with at least 2% probability of colonization (**%2Col** >5). If **HQCL45** or **HQCL85** are >0 of those species, there is even greater support for planting those species.
8. **Identification of species currently present but rare, and potentially suitable for expansion based on SHIFT model:** Some species are present but with a low percentage of occupany now or in the future across the area of interest. Given that most land managers have a preference for planting species in, or at least near, their natural range, these are species that may be candidates for planting to expand their position. We select those species with a **%OccCol** of less than 25% of the area. **%OccCol** is the sum of areas currently occupied (PerOcc) and those areas projected to get occupied at >50% probability within 100 years (Per50Col). We then can use the variables that combine habitat quality and colonization likelihood (**HQCL45** and **HQCL85)** to assist in selecting potential species for planting. Sorting on **%OccCol** provides the list from >0.01 to 25.0; then those species with **HQCL45** or **HQCL85** showing values >0 will have both suitable habitat and some likelihood of colonization with higher values represented higher potentials for those species.

Possible method to assist in selecting candidate tree species to plant

The following is one approach, among others, that decision makers can use to narrow the potential list of species to plant. We assume managers would prefer to select species that are fairly well adapted to predicted future climatological conditions and that are already within, or at least close to, the range of the species. Species models and information concerning adaptability were based on species' natural distributions across their entire range within the United States. Of course some managers, especially those planting in parks or urban areas, will have additional criteria for selection based on factors such as form and safety.

1. **Select species present currently (often common or abundant) that are likely to cope with the changing climate:** for these species, we simply select among those with a Fair, Good, or Very

Good capability to cope under low (**Capabil45**) or high (**Capabil85**) emissions. Coded '1' under **PC**.

2. **Select species present currently, but less common (often rare and often with poor capability classes), yet are potentially in a position to expand over time (see #8 above):** for these species, we select those with an occupancy currently or with at least a 50% likelihood of colonization within 100 years (**%OccCol**) of less than 25%, and then evaluate the combined habitat quality/colonization likelihood weighted score (either **HQCL45** or **HQCL85**) for values >0. The higher the HQCL score, the higher chance the species is appropriate for planting. Keep also in mind the capability, adaptabiliy, and change classes of these species as you narrow your search, as some may just have too many negative factors to consider planting. Coded '2' under **PC**.
3. **Select species not recorded (via FIA) currently, but with potential to migrate into the area of interest within 100 years:** these species are labeled New Habitat under **Capabil45** or **Capabil85**, and also show some chance (**%AnyCol**) of colonization within 100 years. This is an optimistic view because SHIFT is using an optimistic rate of migration of 50 km/century and an optimistic long-distance potential of 500 km. To subset these further, we suggest you especially consider those species with at least a 5% of the area with at least 2% probability of colonization (**%2Col** >5). Coded '3' under **PC**.
4. **Select other species:** we emphasize that these analyses are only to be used as general guidelines for species selection. Our models are intended to reflect reality but will have error. The models are built from FIA data across the eastern US, and for certain species, local influences (e.g., lake effects) will override the general tendencies across the entire eastern US. The models also necessarily are built from coarse-level data and are unable to zero in on special or rare habitats. Therefore, please do not discard species from consideration if they do not show up of the three lists mentioned above, but use your local knowledge to select species that may be suited for particular niches in your project area. Coded '0' under **PC**.

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