Characterizing Tropical Forest Representativeness for Optimizing Sampling Network Coverage

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Quantitative Sampling Network Design

- Resource and logistical constraints limit the frequency and extent of observations, necessitating the development of a systematic sampling strategy that objectively represents environmental variability at desired spatial scales.
- Required is a methodology that provides a quantitative framework for informing site selection and determining the representativeness of measurements.
- Multivariate spatiotemporal clustering (MSTC) was applied at the landscape scale (4 km $\times$ 4 km) globally to demonstrate its utility for representativeness and scaling.
- Method recently used to quantify representativeness of candidate sampling sites for the State of Alaska (Hoffman et al., 2013).
- An extension of the method applied by Hargrove and Hoffman for design of National Science Foundation's (NSF's) National Ecological Observatory Network (NEON) domains (Schimel et al., 2007; Keller et al., 2008).

Ecoregions

Table 1: *17 data layers used for this analysis (Potter and Hargrove, 2013).*

Variable Description	Units
Bioclimatic Variables	
Precipitation during the hottest quarter	mm
Precipitation during the coldest quarter	mm
Precipitation during the driest quarter	mm
Precipitation during the wettest quarter	mm
Ratio of precipitation to potential evapotranspiration	unitless
Temperature during the coldest quarter	°C
Temperature during the hottest quarter	°C
Day/night diurnal temperature difference	°C
Sum of monthly T_{avg} where $T_{avg} \geq 5°C$	°C
Integer number of consecutive months where $T_{avg} \geq 5°C$	unitless
Edaphic Variables	
Available water holding capacity of soil	unitless
Bulk density of soil	g/cm^3
Carbon content of soil	g/cm^2
Nitrogen content of soil	g/cm^2
Topographic Variables	
Compound topographic index (relative wetness)	unitless
Solar interception	kW/m^2
Elevation	m

10 Global Ecoregions, Random Colors

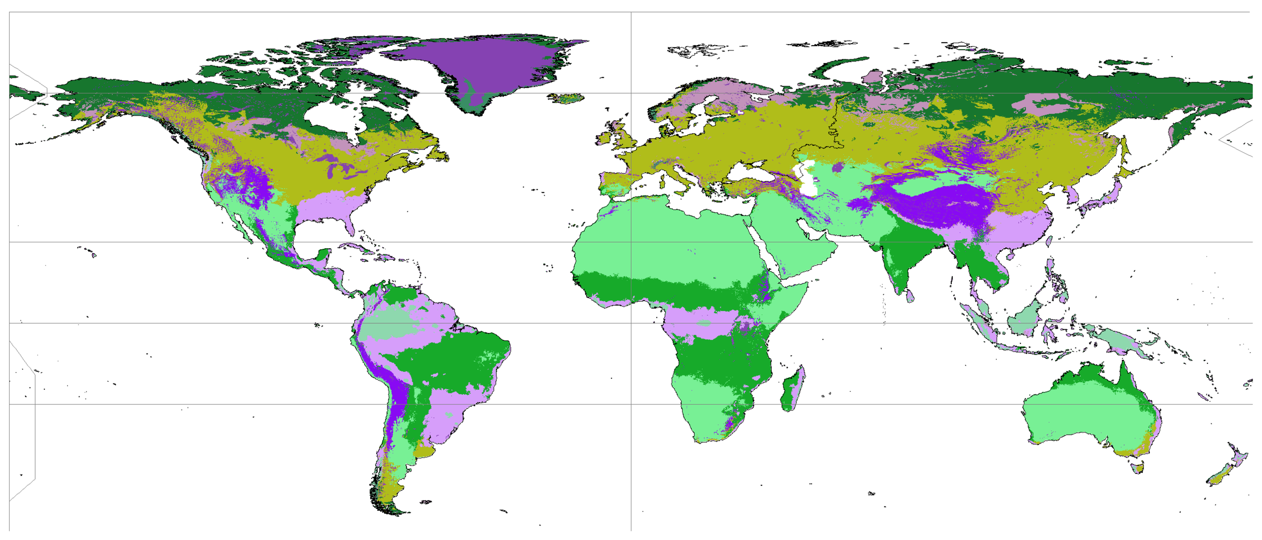


Figure 1: *The 10 most different ecoregions globally are shown in random colors. Notice that areas with similar environmental characteristics are colored the same no matter where they occur on Earth.*

50 Global Ecoregions, Random Colors

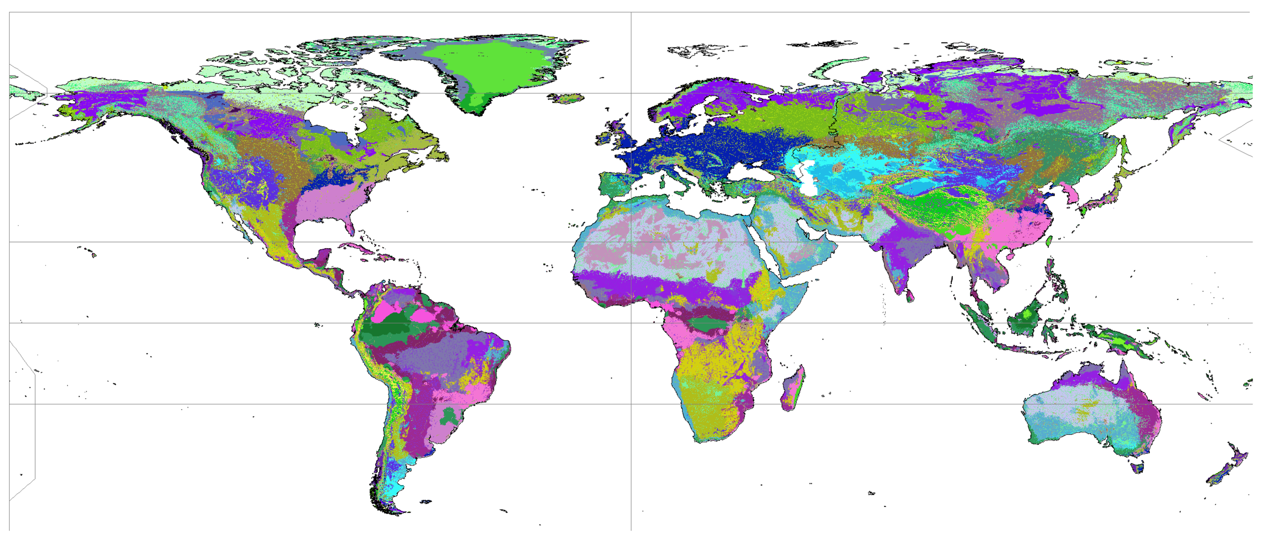


Figure 2: *The 50 most different ecoregions globally are shown in random colors. Notice that areas with similar environmental characteristics are colored the same no matter where they occur on Earth.*

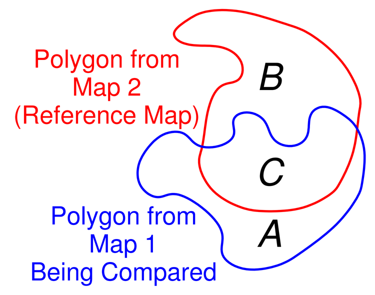
Label Stealing

Automated Supervision for Unsupervised Classification

- Clustering is an unsupervised classification technique, so ecoregions have no descriptive labels (e.g., **Eastern Deciduous Forest Biome**).
- **Label stealing** allows us to perform automated "supervision" by "stealing" the best corresponding human-created descriptive labels to assign to ecoregions.
- We employ a tool called **Mapcurves** to select the best ecoregion labels from ecoregionalizations delineated by human experts.
- We consider an entire library of ecoregion and land cover maps, and choose the label with the highest **goodness-of-fit (GOF)** score for each ecoregions polygon.

Mapcurves: A Method for Comparing Categorical Maps

- Hargrove et al. (2006) developed a method for quantitatively comparing categorical maps that is
  - independent of differences in resolution,
  - independent of the number of categories in maps, and
  - independent of the directionality of comparison.

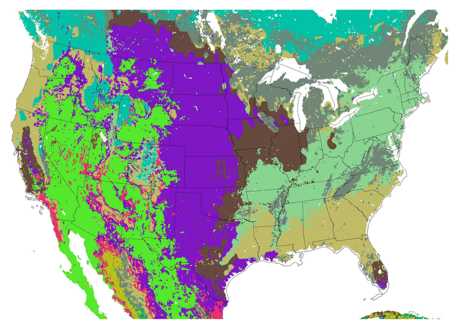


Goodness of Fit (GOF) is a unitless measure of spatial overlap between map categories:

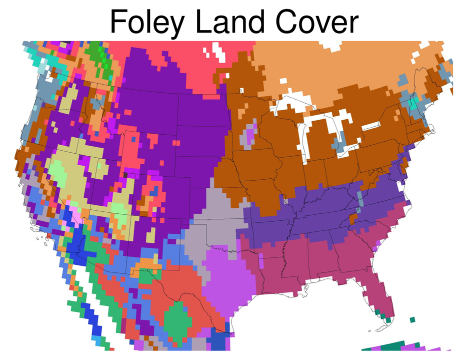
$$\text{GOF} = \sum_{\text{polygons}} \frac{C}{B+C} \times \frac{C}{A+C}$$

- GOF provides "credit" for area of overlap, but also "debit" for area of non-overlap.
- Mapcurves comparisons allow us to reclassify any map in terms of any other map (*i.e.*, color Map 2 like Map 1).
- A grayscale GOF map shows the degree of correspondence between two maps based on the highest GOF score.

Expert-Derived Land Cover/Vegetation Type Maps



Foley Land Cover



Holdridge Life Zones

Expert Map	# Cats
1. DeFries UMd Vegetation	12
2. Foley Land Cover	14
3. Fedorova, Volkova, and Varlyguin World Vegetation Cover	31
4. GAP National Land Cover	578
5. Holdridge Life Zones	25
6. Küchler Types	117
7. BATS Land Cover	17
8. IGBP Land Cover	16
9. Olson Global Ecoregions	49
10. Seasonal Land Cover Regions	194
11. USGS Land Cover	24
12. Leemans-Holdridge Life Zones	26
13. Matthews Vegetation Types	19
14. Major Land Resource Areas	197
15. National Land Cover Database 2006	16
16. Wilson, Henderson, & Sellers Primary Vegetation Types	23
17. Landfire Vegetation Types	443
18. ESA Global Land Cover	23

50 Ecoregions Reclassified by Label Stealing

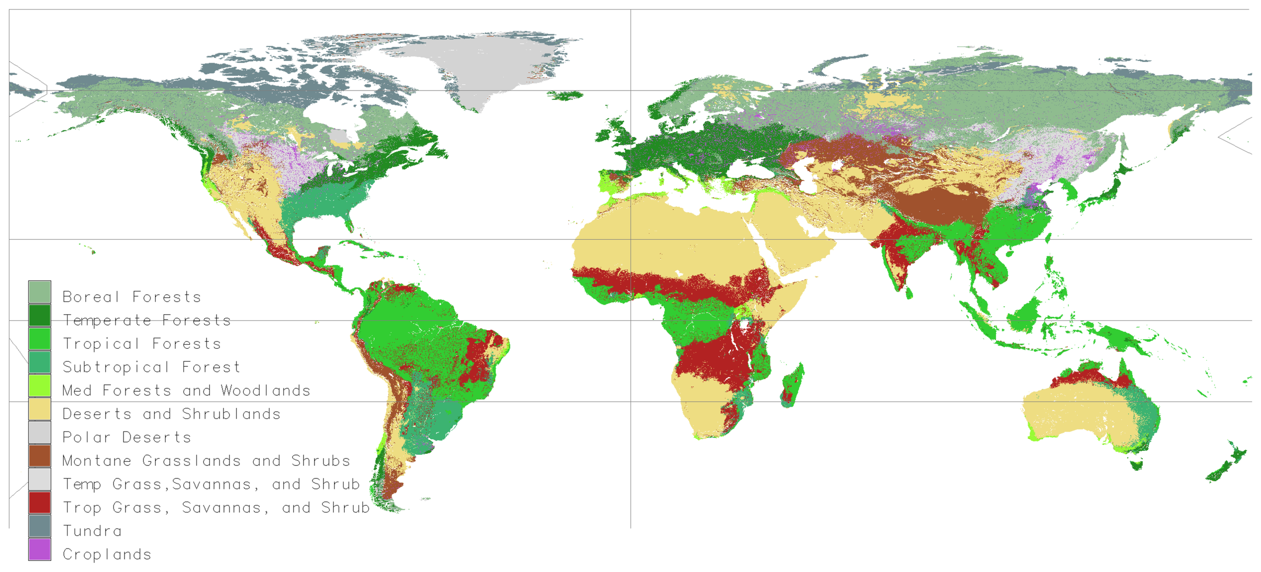


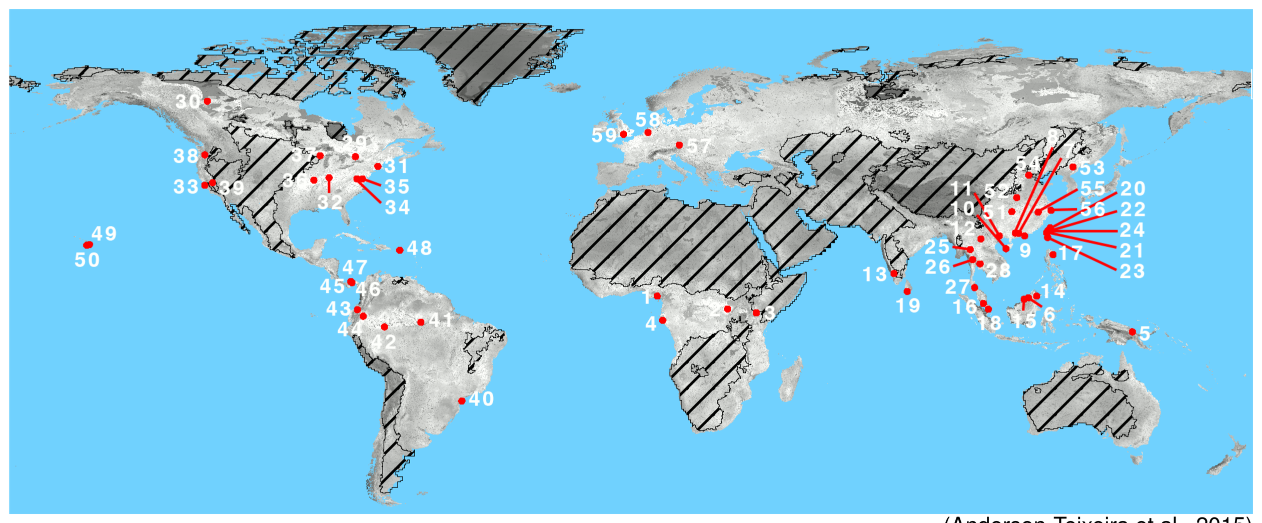
Figure 3: *The 50 quantitatively derived global ecoregions are reduced to 12 broadly defined land cover classes through the Label Stealing process.*

Representativeness

Global Forest Site Representativeness

- Representativeness analysis uses the standardized *n*-dimensional data space formed from all 17 input data layers shown in Table 1.
- In this data space, the Euclidean distance between a sampling location (like Manaus, Brazil) and every other point is calculated.
- Data space distances are used to generate grayscale maps showing the degree of similarity, or lack thereof, of every location to the sampling location.
- Below, white areas are well represented by the sampling location or network, while dark and black areas as poorly represented by the sampling location or network.

ForestGEO Network Global Representativeness



(Anderson-Teixeira et al., 2015)

Figure 4: *Map of ForestGEO network representation. Stippling covers non-forest areas as determined by Label Stealing.*

Triple-Network Global Representativeness

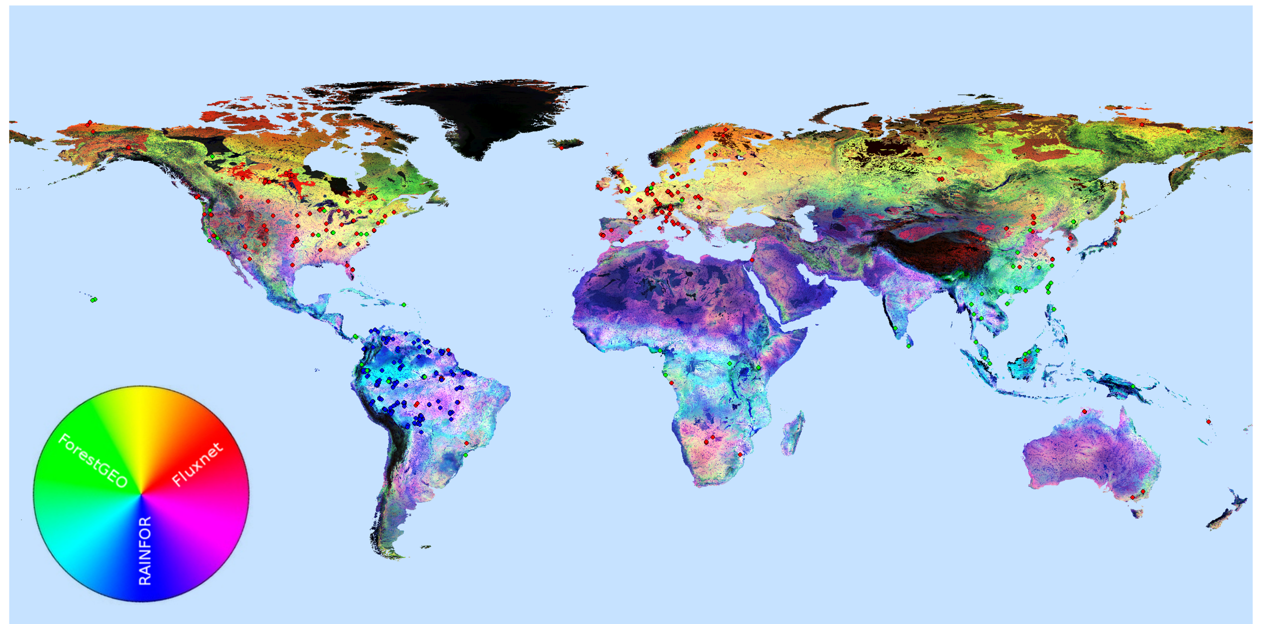


Figure 5: *Map indicates the sampling networks that offer the most representative coverage for any location. Every location is made up of a combination of three primary colors from Fluxnet (red), ForestGEO (green), and RAINFOR (blue).*

Conclusions and Next Steps

- **Multivariate Spatiotemporal Clustering (MSTC)** provides a quantitative framework for stratifying sampling domains, informing site selection, and determining representativeness of measurements.
- **Label Stealing** offers a useful means for interpreting and understanding ecoregion or sampling domain delineation.
- **Representativeness Analysis** provides a systematic approach for up-scaling point measurements to larger domains.
- Methodology is independent of resolution and surrogate data, thus can be applied from site/plot scale to landscape/global scale with site measurements, remote sensing, and models.

Next Steps for Tropical Site Selection

- Input data layers must be selected to capture important environmental gradients related to carbon cycle drivers.
- A more careful analysis of existing sampling sites should consider type, frequency, and protocol of measurements.
- Observation data may be paired with projected changes in climate and atmospheric CO_2 levels to estimate how ecoregions may reorganize in the future.
- Method will be used to develop an optimized network of tropical forest sampling sites to answer key science questions.

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