**Exploring Landscape Metrics through Galápagos Tortoise GPS Locations**

**Introduction**

Landscape ecology is the science of pattern-process relationships and how these spatio-temporal patterns drive ecological processes (Turner 1989). Landscape structure consist of attributes that depict landscape composition and landscape configuration, where composition details the abundance and variety of landscape elements while configuration usually measures pattern and configuration of landscape elements (Cushman & McGargical 2019). All pattern-process relationships depend on the researcher’s choice in being able to correctly define their landscape of choice relative to the dominant drivers of present ecological characteristics (Wu 2004).

Landscape metrics can be deemed as essential methods to allow researchers and managers to assess large scale ecological conditions in landscapes over varying spatial and temporal scales and under alternative scenarios (Cushman & McGarigal 2019). In combination with monitoring tools to track various faunal and floral species, it is then possible to explore how landscape metrics may provide insight on the potential connectivity and movement resources for an organism.

My objectives for this case study were to quantify landscape patterns at various levels (landscape and patch), describe its structure and composition, and relate it to tortoise movements on the landscape.

**Methods**

*Study area and data collection*

I obtained a detailed land cover classification map of agroecosystems of the Galápagos Islands (Laso et al. 2020). The map detailed high-resolution coverage of agricultural zones and habitat for surrounding protecting areas, where images were obtained from Sentinel-2 and PlanetScope and verified with images collected from unmanned aerial vehicles. Images were taken in 2018; thus, the temporal resolution of the product map was an indicator of land cover for 2018.

I used the R package `stars` to rasterize the land cover map and assigned land cover classes to corresponding raster cells. There were 20 classes that fell into two categories: introduced and native cover. Introduced cover categories include cedar, quinine, coffee, porotillo, supirosa, mixed forest, permanent crops, elephant grass, guava, blackberry, silvopasture, pomarrosa and transitory crops. Native land cover categories include deciduous forest, evergreen forest and shrubland, evergreen seasonal forest and shrubland, humid tallgrass, and pioneer. More detailed descriptions of each land cover category can be found in Table 2 and Table 2 from Laso et al. (2020).

I then used the land cover raster to analyze various landscape, patch and class metrics using the open-source R package `landscapemetrics` (Hesselbarth et al. 2019); `landscapemetrics` is based off the popular FRAGSTATS software (McGarigal et al. 2012). `landscapemetrics` provides many utility functions to sample landscape metrics in a tidy workflow, which can then be used to provide data visualizations of landscape characterizations and analyzed metrics.

*Galápagos tortoise movement data*

I obtained a dataset of the Galápagos Tortoise Movement Ecology Programme from the

MoveBank data repository (Bastille-Rousseau et al. 2016). Galápagos tortoises are large-bodied, ectothermic terrestrial herbivores that are distributed on the larger islands throughout the Galápagos Archipelago (Bastille-Rousseau et al. 2019). Between 2009 and 2014, three species of adult tortoises were tagged with custom-made GPS tags on three different islands. Geographic locations of tortoises were obtained at a fixed one-hour interval rate from the GPS tags.

I chose to focus on tortoises that inhabited Santa Cruz Island East. I used a subset of the GPS data by filtering for tortoises that inhabited Santa Cruz East and location data that occurred during 2018. I set the agricultural landcover map as the spatial extent; therefore, I clipped tortoise locations that fell outside of the area bounding box.

Having two spatially explicit datasets, I was then able to analyze the location and landscape cover data concurrently by extracting raster cells where tortoise locations were present. Both location and landcover data had the same projection (WGS 84 / UTM zone 15S). `landscapemetrics` provides functions made to sample around points of interests (tortoise locations). I used various functions such as `landscapemetrics::extract\_lsm()` and `landscapemetrics::sample\_lsm()` to determine patch metrics related to tortoise locations.

**Results**

I used the `sf` (Pebesma 2018) and `stars` (Pebesma, unpub.) geospatial R packages to plot tortoise locations on top of the Santa Cruz Island landcover raster (Fig. 1). The highest amount of landcover (hectares) include native cover of forest (evergreen seasonal forest and shrubland and deciduous forest, while the highest introduced cover was cedar and silvopasture (Fig. 2).

Graphical user interface

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Figure

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*Study area landscape metrics*

At the landscape level, the total area of core patches found (TCA) equaled to 11,458 hectares with mean size 1.37 hectares and standard deviation 47.0 hectares. The mean core area index (CAI\_MN) was 0.485, while the aggregation index was 63.9. At the patch level, Pearson’s correlation method was used to determine correlation of patch level metrics of the Santa Cruz Island landscape (Fig. 3).

Chart, bar chart

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Figure

*Extracting landscape metrics with tortoise locations*

The `landscapemetrics::extract\_lsm()` function was used in combination with tortoise locations to observe how each tortoise selected each core area, at the patch level (Fig. 4). Because n tortoise = 6, I was able to track the individual summation of core area used by each tortoise with the corresponding tortoise ID.

**Discussion**

Upon visual inspection of the Fig. 1 map, it appears that tortoises mostly spend time in forest areas within protected areas and then briefly travel through some areas of agroecosystems. When conditioning upon core patch areas across the landscape, tortoises were confirmed to be heavily present in forest areas, with minimal observations in pioneer, Psidium-guava and silvopasture agriculture areas. While there are further analyses that needs to be implemented to infer that tortoise movement presents potential human-wildlife interactions and conflicts in the future, the combination of using GPS location data and land cover maps provides a brief look at how tortoise connectivity may be disrupted by agroecology practices. For example, tortoises heavily use core areas of forests mostly found within the protected areas but may occasionally travel through agricultural areas. We can further explore different landscape metrics related to tortoise movements; determining the correlation of metrics also provides insights on whether potential multicollinearity issues may arise.

Chart, waterfall chart

Description automatically generated

Figure

I merely used raw GPS location data as a proxy for tortoise habitat selection, which falls under the assumption that a recorded point the tortoise is preferentially choosing to “select” that particular component of the landscape. For example, while dispersing, a GPS point may have been recorded during an animal’s moment of travelling and locomotion. However, there is an immense amount of literature focused on animal habitat selection models, where most studies are based on a resource selection function (RSF) model that utilizes a logistic regression framework (Boyce et al. 2002). These frameworks fall under the theme of aiming to calculate animal probabilities of habitat selection as a function of habitat use (recorded animal locations) and habitat availability (classification of randomized habitat plots, “available” on the landscape).

Choice of landscape metric matters, as it can lead to opposite conclusions regarding the current landscape; often times, a multivariate approach is necessary to evaluate several metrics concurrently (Cushman & McGarigal 2019). Thus, when considering using RSF models along with landscape metrics, it is important to determine the appropriate spatial scale when conducting a connectivity analysis. Further and more in-depth studies can include determining an RSF for the tortoise dataset, creating a resistance layer to determine connectivity areas while calculating metrics for the appropriate sized scale landscape.

**References**

1. Bastille-Rousseau G., J.R. Potts, C.B. Yackulic, J.L. Frair, E.H. Ellington, and S. Blake. 2016. Data from: Flexible characterization of animal movement pattern using net squared displacement and a latent state model. Movebank Data Repository. doi:10.5441/001/1.356nb5mf
2. Bastille-Rousseau, G., C. B. Yackulic, J. L. Frair, F. Cabrera, and S. Blake. 2016. Allometric and temporal scaling of movement characteristics in Galapagos tortoises. L. Börger, editor. Journal of Animal Ecology 85:1171–1181.
3. Bastille‐Rousseau, G., C. B. Yackulic, J. P. Gibbs, J. L. Frair, F. Cabrera, and S. Blake. 2019. Migration triggers in a large herbivore: Galápagos giant tortoises navigating resource gradients on volcanoes. Ecology 100:e02658.
4. Boyce, M. S., P. R. Vernier, S. E. Nielsen, and F. K. A. Schmiegelow. 2002. Evaluating resource selection functions. Ecological Modelling 157:281–300.
5. Cushman, S. A., and K. McGarigal. 2019. Metrics and Models for Quantifying Ecological Resilience at Landscape Scales. Frontiers in Ecology and Evolution 7:1–21.
6. Hesselbarth, M. H. K., M. Sciaini, K. A. With, K. Wiegand, and J. Nowosad. 2019. landscapemetrics : an open‐source R tool to calculate landscape metrics. Ecography 42:1648–1657.
7. Laso, F. J., F. L. Benítez, G. Rivas-Torres, C. Sampedro, and J. Arce-Nazario. 2020. Land cover classification of complex agroecosystems in the non-protected highlands of the Galapagos Islands. Remote Sensing 12.
8. Pebesma, E. 2018. Simple Features for R: Standardized Support for Spatial Vector Data. The R Journal, 10:1 439–446.
9. Turner, M. G. 1989. Landscape Ecology: The Effect of Pattern on Process. Annual Review of Ecology and Systematics 20:171–197.
10. Wu, J. 2004. Effects of changing scale on landscape pattern analysis: scaling relations. Landscape Ecology 19:125–138.

**Data Accessibility Statement**

All datasets are publicly available, and all statistical analyses are fully reproducible. The agroecology landcover classification of Galápagos can be accessed via supplementary information from Laso et al. 2020. The Galápagos tortoise movement location data originated from the Galápagos Tortoise Movement Ecology Programme and can be accessed through the MoveBank platform (Bastille-Rousseau et al. 2016).

Reproducible R scripts can be downloaded at <http://github.com/nannourn/FOR870/> corresponding with the “final.Rproj” R project file.