Evaluating the Spider Community of Sulawesi along Elevational Change and Forest Cover Loss

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ABSTRACT

Due to their consistent temperature and long-term isolation, tropical islands contain a majority of the global biodiversity. Within the last few decades, forests in Southeast Asia in particular has experienced some of the highest losses of forest cover caused by monoculture plantations. Past studies have linked anthropogenic disturbance and landscape changes to negatively impact the species community of islands, yet many have neglected to holistically implement how historical processes also play a role. As one of the world's largest islands situated in between Indonesia and Australia, Sulawesi provides an ideal setting to study both past and modern changes. Sulawesi has undergone geological transformations due to past tectonic collisions, unifying land masses that held their own unique compilation of biota. Within the island, spiders can be used to study effects from elevational gradients and forest cover, which represent the two types of changes the island has experienced. Spiders are the fourth most diverse order of species and can be found in almost all kinds of environment. Using data from a sampling period, I quantified the land cover change in the two mountain sites of interest and identified how spiders compare across elevation and forest cover. I found that species diversity is lowest at the highest elevations and maximizes with higher forest cover when it is not affected by the harsh environment of higher elevations. As preluded by this finding, factors from differing types of modifications must be considered in future studies, especially in areas with major geological changes and high-intensity disturbance.

KEYWORDS

geospatial analysis, evolutionary ecology, arthropods, island dynamics, land cover classification

INTRODUCTION

Tropical islands are often regarded as biodiversity hotspots for providing increased primary productivity and climatic stability to support various kinds of species. Larger areas of habitat in the tropics also drive higher speciation rates and lower extinction rates, allowing species richness to thrive (Mittelbach et al. 2007). Due to these factors and limitations of species dispersing elsewhere, islands have higher rates of endemism compared to most mainland (Sivaperuman et al. 2008). The magnitude of endemism correlates with geographic isolation, as barriers reduce competition and immigration rates (Fordham and Brook 2010). Environmental stability, such as the consistent temperature of the tropics, is also pertinent to support adaptive radiation within species (Gillespie 2016, Jansson 2003). Sulawesi is one of the islands that make up a popular hotspot known as Wallacea, in which over 60% of mammals, reptiles, and amphibians in the region are endemic (Conservation International 2004). Land fragments that make up Sulawesi are notable in particular due to their differing origins, the Asian and Australian tectonic plates. The overlap produced a unique combination of biota on the island (Lohman et al. 2011). In addition, modern processes such as anthropogenic effects also serve as factors to consider in understanding the dynamics of species on the island.

Similar to other tropical forests in Southeast Asia, increased loss of forest cover in Sulawesi is especially threatening to the high amount of endemic species in the area. Before late 1970's, the Indonesian government heavily focused on producing wet rice in Sulawesi; however, during the 1980's, this pattern switched to cash crops for exports. Monoculture plantations are currently still the main cause of land use conversions in Central Sulawesi, mostly from growing cacao and palm trees (Weber et al. 2007). From 1990 to 2010, Sulawesi lost 7.54 Mha of primary forest, with lowland areas experiencing the most loss (Margono et al. 2012, Miettinen et al. 2011). Increased habitat fragmentation in Southeast Asian islands has a significant association with reduced species richness, population growth rate, and breeding successes (Fahrig 2003, Sodhi et al. 2004). As a result, heavily disturbed species may experience the extinction threshold, a level below which the population would not be able to sustain itself (Flather and Bevers 2002). Due to intense deforestation, Sulawesi's lower elevational areas have experienced multitudes of change whereas the higher-elevation areas remain more isolated and stable (Harris et al. 2014, Floren and Deeleman-Reinhold 2005).

To further solidify environmental factors related to species richness, the spider population of Sulawesi can be used as a metric in understanding effects from elevational gradients and forest cover. Spiders are some of the most abundant and diverse groups of species that exists (Buchholz 2010, Ossamy et al. 2016). Furthermore, they have previously been used to compare various habitats' effects on species distribution, as they quickly respond to both natural and anthropogenic disturbances (Maelfait 2002, Ossamy et al. 2016, Pearce and Venier 2006). Within a past study in Sulawesi, richness of spider biodiversity peaked in mid-altitudes and decreased as elevations increased, due to dominance by few species at higher elevations (Russell-Smith and Stork 1994). This hump-shaped pattern is also related to the limitation of spider dispersal on higher elevations (Foord and Dippenaar-Schoeman 2016). Since higher elevation communities are more isolated and inaccessible, the rate of anthropogenic activities and species migration decline as altitude increases (Lomolino 2001). Quantifying how families of spiders differ in biodiversity across elevational gradients in Sulawesi can represent a comparison of how a community of species differs between historically affected upper elevations and recently deforested lowlands.

After identifying how the distribution of spiders compare, I will analyze how historical and modern processes have affected the biodiversity of spiders in Sulawesi. I will a) quantify the temporal change in landscape caused by loss of forest cover from 2015 - 2018, b) compare spider's species composition in relation to forest cover, and c) compare species composition across elevational change. By comparing Landsat imageries, I expect that loss of forest cover in the lowlands has increased as a result of land conversion to monocultures in the past couple of decades, while upper areas remain isolated. Spider species will be more diverse around mid-altitudes, where there is a mix of habitats that can support various roles. I also expect higher species diversity at sites with higher coverage of forests. I will confirm these hypotheses by classifying land cover change and studying the distribution of sampled spiders that were geolocated on the island.

METHODS

Study site

Sulawesi is one of many islands that compose Indonesia, which is located in Southeast Asia (Figure 1). Sulawesi's interior is mostly made up of non-volcanic mountains. Its temperature is relatively constant and ranges from 25.4 °C to 26.2 °C. The island's precipitation level varies with elevation and topography, although it typically ranges from 169.8 mm to 292.4 mm (The World Bank Group 2016). From May to October, Sulawesi undergoes a dry season, and from November to April, it undergoes a rainy season (Katili 1978). The island's vegetation regularly experiences drought events caused by El Nino-Southern Oscillation (Tanasevich and Stenchly 2012). Sulawesi is the largest island within Wallacea, a category for a group of islands separated by straits from continental shelves in Indonesia. Millions of years ago, the Asian and Australian tectonic plates collided and separated from the continents, resulting in paleo-islands that make up Sulawesi (Katili 1978). Each fragment carried distinct types of species and plants, resulting in a faunal boundary named Wallace's line in between Asia and Australia (Bacon et al. 2013, Mayr 1994). Geological changes throughout the Miocene and Pliocene eras also produced a wider range of elevations, creating more variety in lowlands and mountains (Lohman et al. 2011, Eldridge et al. 2018). Due to the overlap of biota from characteristic origins, a range of habitats, and consistently stable tropical climate, the island is considered a major hotspot for biodiversity with an abundance in endemic species (Sodhi et al. 2004).

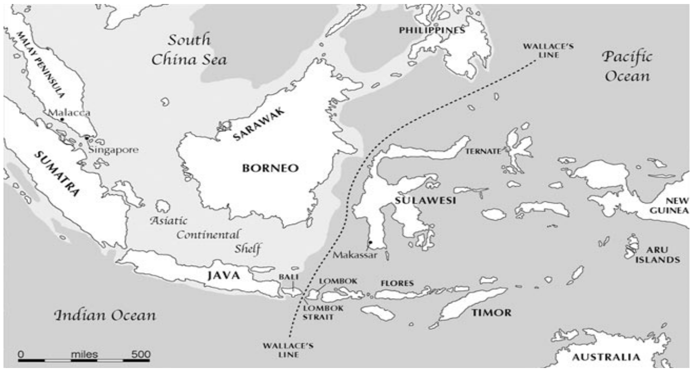


Figure 1. Geographical location of Sulawesi in Indonesia. Sulawesi is located directly next to the Wallace Line, a well-known biogeographical boundary. (*Source: Gaines 2011)*

Data sources

Spider collection

To determine spider species distribution, I used specimens collected and sorted by Anna Holmquist and her team, funded by the National Science Foundation. On the summer of 2018, Holmquist collected along an elevational gradient on two mountains in Sulawesi, each on separate paleo-islands. The two mountains Holmquist sampled on were Galang Mountain and Torompupu Mountain, indicated by the green and yellow markers, respectively (Figure 2). Galang Mountain is more accessible and experiences more disturbance from plantations and urbanization, whereas Torompupu is more isolated. Holmquist sampled at 400-meter intervals and collected at least four replicates per elevational band. Each site was a standardized size of 20 by 20 meters.

Figure 2. Google Maps imagery of the two mountain sites: Galang (green) and Torompupu (yellow). The map shows the geographical distance between the mountains.

To create a complete database, Holmquist sampled spiders on each mountain using pitfall traps, beat sheets, hand collection, leaf litter analysis, and web documentation. She set two pitfall traps, which were left for five to seven days. Holmquist conducted beat sampling for two minutes in total, in which she collected spiders that fell out from beating trees. She collected for one hour during the day and for two hours during the night per site. Lastly, Holmquist collected leaf litter at each site, gathering a similar volume each time by filling a two-gallon bag. She sorted the litter by hand to remove spiders and other arthropods. Holmquist used a Global Positioning System tracker to mark each spider's coordinates.

Landscape imagery

To quantify temporal landscape changes from loss of forest cover, I first downloaded Landsat 8 Surface Reflectance products from USGS EarthExplorer (USGS 2019). I chose imageries that were taken from the same dry season in which Holmquist sampled for both 2015 and 2018, which is from May to August (Erasmi et al. 2004). In addition, I selected imageries based on resolution quality and amount of cloud coverage. Each imagery I downloaded included 10 bands. Bands 1 to 7 had visible light and infrared light information, and the other three bands were used for quality analysis. I used software ArcMap (ESRI 2011), QGIS (QGIS Development Team 2018), and R Studio (R Core Team, 2018) to preprocess the imagery data and to perform supervised classification of forest covers (Horning 2013).

Data processing

To mask clouds from imageries, I loaded the "pixel quality analysis" band from Landsat 8 products on ArcMap 10.6. I identified the cloud values using the Identity tool and reclassified the band to binary data using the Raster Calculator tool. In the new binary imagery, the cloud values are 0, and all other non-cloud values are 1. To apply the masked clouds across bands 1 to 7 from each imagery, I utilized the ModelBuilder extension from ArcMap (Figure 3). I added bands 1 to 7 as the input and applied a conditional to only iterate the process through raster file types in order to exclude TXT files that also come with Landsat imageries. Then, I added a Raster Calculator tool to mask clouds from each band by multiplying the binary data with all other bands. I ran through the model to apply these changes, and I added the output layers to ArcMap's Table of Contents. The new output bands had clouds with a value of 0. Using Image Analysis, I created a composite of the bands, resulting in a complete, cloud-free imagery of each site.

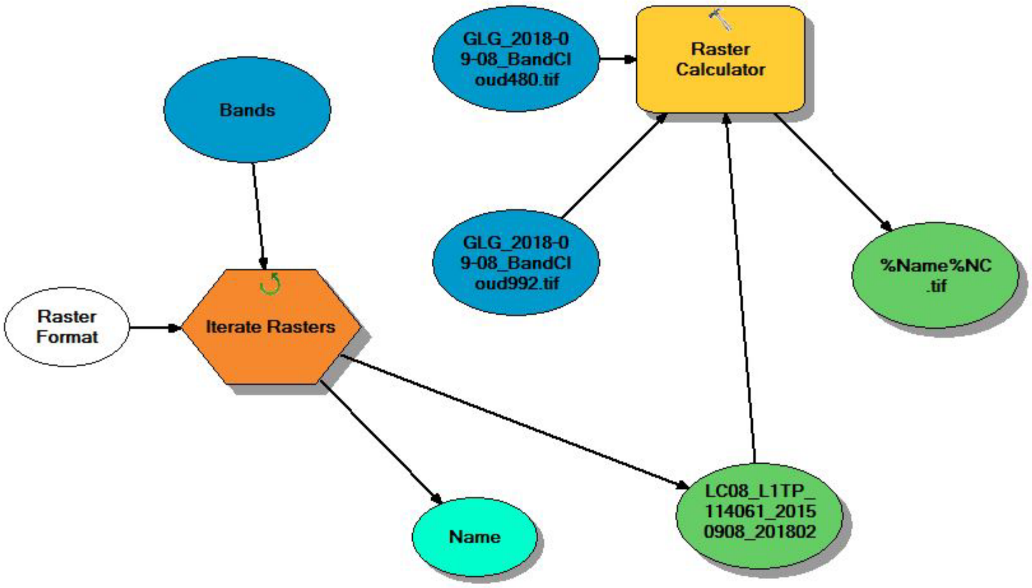


Figure 3. ModelBuilder tool to mask clouds on ArcMap 10.6.

Geospatial analysis

Forest cover loss quantification

To visualize land cover change, I utilized a false-color display to highlight areas of live vegetation and lack thereof. I displayed Short-wave Infrared Reflectance (SWIR) through the red band, the Near Infrared Reflectance (NIR) through the green band, and the red reflectance through the blue band. As a result, I displayed the forests as green and the non-forests as red, since live plants strongly reflect NIR and non-live plants reflect SWIR. Then, I quantified the Normalized Difference Vegetation Index (NDVI) for each year and calculated the differences in NDVI between the two years (Figure 4).

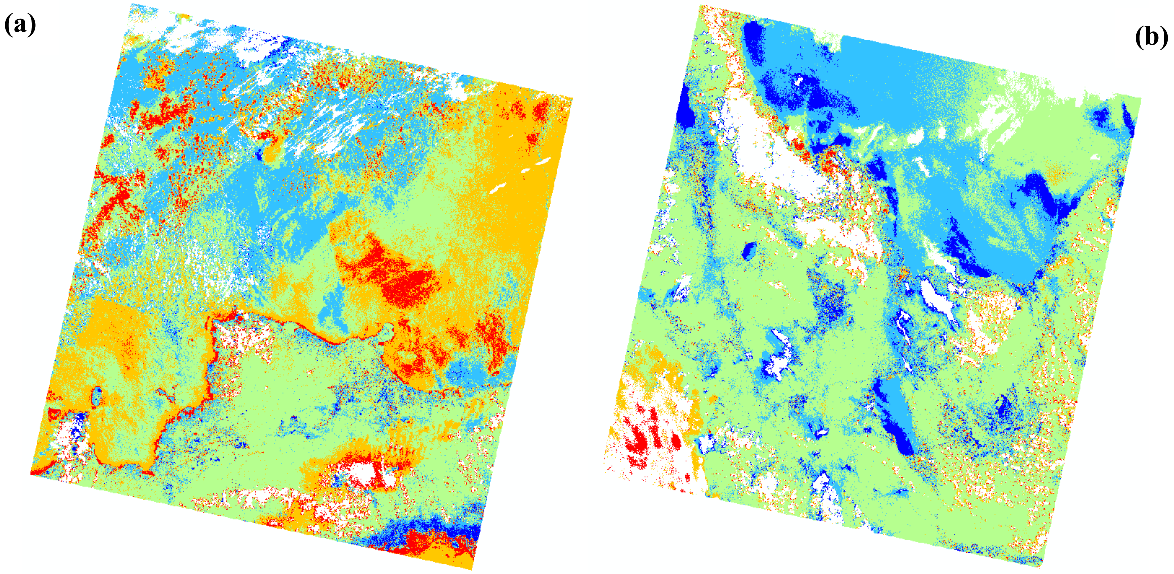


Figure 4. Imageries of NDVI differences between 2015 and 2018 for (a) Galang and (b) Torompupu mountain imageries. Red indicates change from forest to non-forest, blue indicates change from non-forest to forest, and yellow-green indicates no change. White indicates the masked clouds.

To generate training sites for a supervised classification, I drew and assigned polygons to various areas of the island that either experienced a change in forest cover or stayed constant from 2015 to 2018. I drew 20 polygons for each class, for a total of four classes: "Forest to Non-Forest", "Forest to Forest", "Non-Forest to Forest", and "Non-Forest to Non-Forest". I used the NDVI images to confirm that the drawn polygons are accurately representative of the changes between the two imageries. To classify the set using the training set data, I ran Horning's code on R Studio (Horning 2013). I produced two final imageries: the forest cover change from 2015 to 2018 in Galang and Torompupu, respectively.

Statistical analysis

Forest cover calculation

To study the surrounding landscape of sampled sites, I generated a 200-meter radius buffer around each transect Holmquist collected on. Then, I used the Tabulate Intersection tool on ArcMap to measure the percentage and the area of each of the four classifications within a buffer.

I used Table Join to combine this information with the spider collecting database, using site name as the primary key from each data.

Elevational community visualization

To analyze the relationships between communities of species and elevation, I ran Non-Metric Multidimensional Scaling (NMDS) on R Studio, which plots sites' similarities based on overlaps in input factors (R Core Team 2016). For the particular case, I analyzed the similarities within the six elevational groups with spider species as the driving factor.

Forest cover and elevation effects on species composition

To confirm that the sites species composition's differences, I calculated the Simpson's Diversity Index for each site on R (R Core Team 2016), which I used to visualize across forest cover area and elevation, respectively. Simpson's Diversity Index is lowest at 0 and highest at 1. I also used the *adonis* function within the package "vegan" (R Core Team 2016) to calculate both the beta diversity indices and Bray-Curtis dissimilarity indices across the sites. While the Bray-Curtis dissimilarity ranks the sites' differences based on species composition, beta diversity takes alpha diversity and the unique number of species into account to compare the sites.

Confirmation of results

To verify the significance of elevational change and forest landscape effects on species diversity, I confirmed my results by running Permutational Multivariate Analysis of Variance (PERMANOVA). After calculating the beta diversity of sites on R Studio, I used the resulting matrix as the response variable in running PERMANOVA. I used the elevational change and forest to non-forest percentage as explanatory variables. I repeated the step using Bray-Curtis dissimilarity indices as the response variable.

RESULTS

Geospatial analysis

Forest cover loss quantification

I created a land cover change map of each mountain with the sampled sites and classifications (Figure 5). Within Galang, the lower elevation sites were most affected by changes from forest to non-forest. Sites A to D in particular experienced various exposures to forest cover loss. Within Torompupu, none of the sites experienced forest cover loss; however, part of site B's surroundings was classified as non-forest to forest.

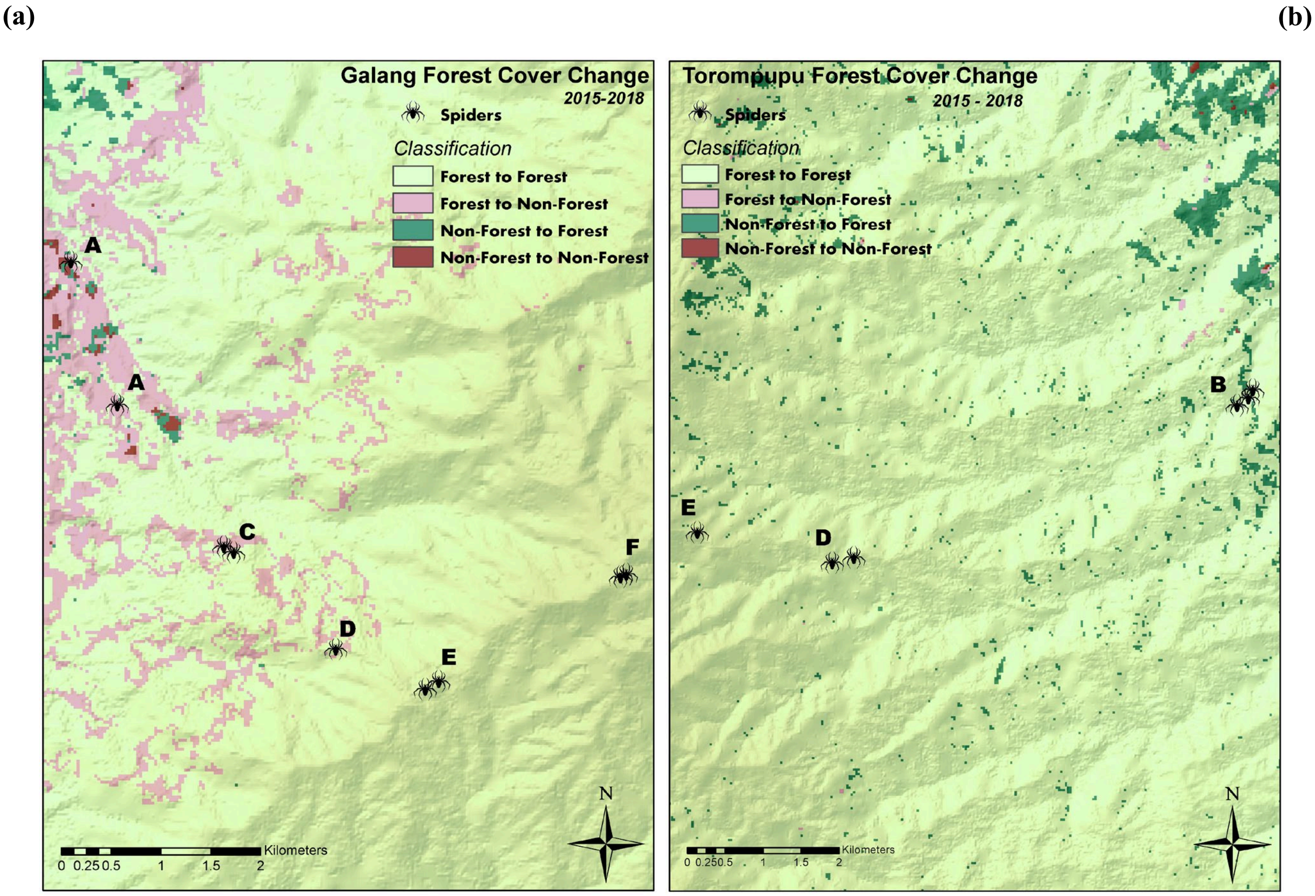


Figure 5. Maps of forest change classifications on (a) Galang and (b) Torompupu mountains on ArcMap 10.6. Letters represent elevational transect, with A as the lowest elevation and F as the highest elevation. Lower sites on Galang share a large proportion of pink land cover, whereas none is found on Torompupu.

Statistical analysis

Forest landscape calculation

Within Galang, there was a dramatic decrease in the change from forest to non-forest percentage across elevation (Figure 6a). At the lowest site, the change percentage was the highest at 59% (Table 1a). It decreased to 0% at the two highest elevations, E and F. Within Torompupu, the change from forest to non-forest percentage was 0% throughout the three elevational groups (Table 1b). There was a slight decrease in the change from non-forest to forest percentage across elevation (Figure 6b). At the lowest site, the change percentage was the highest at only 11% (Table 1b).

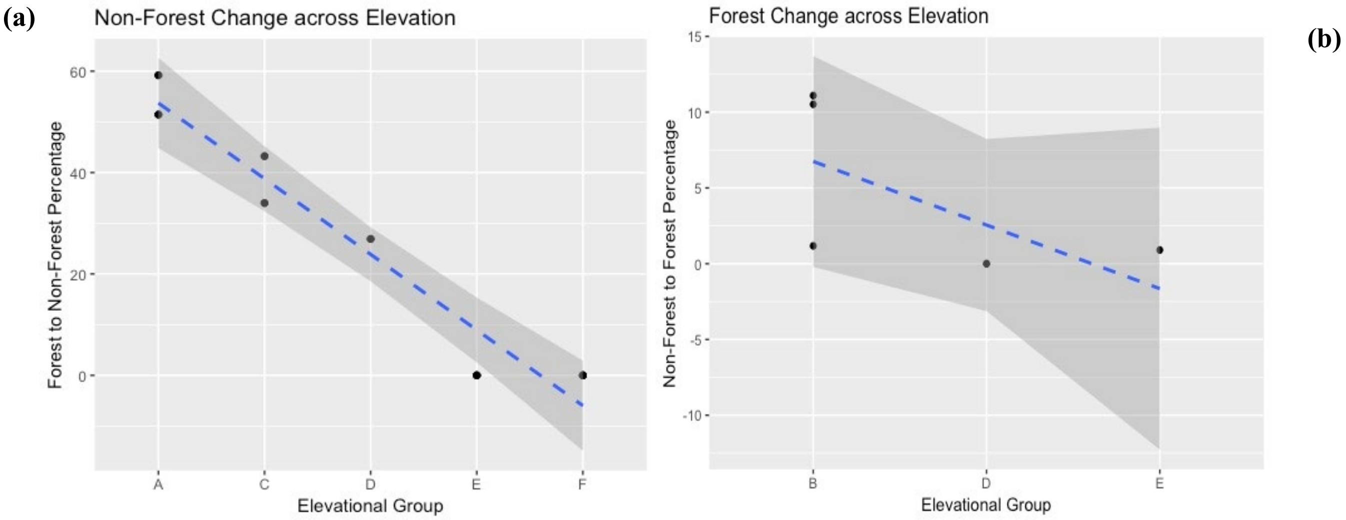
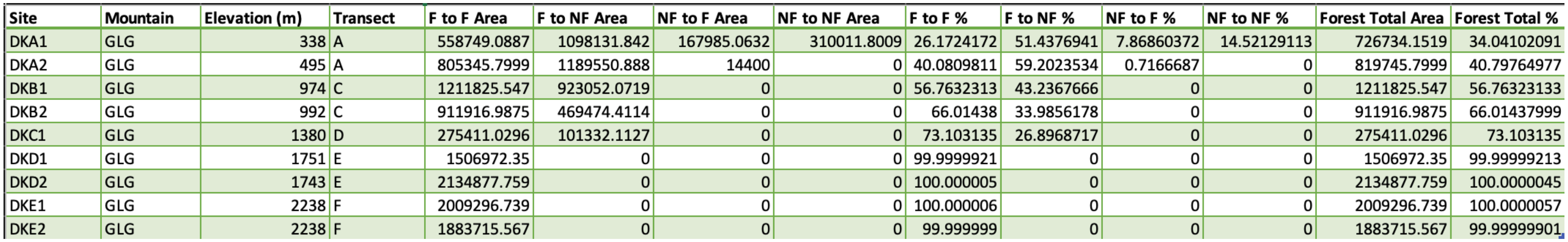


Figure 6. Change from forest to non-forest percentage on (a) Galang and change from non-forest to forest percentage on (b) Torompupu. The y-axis scales of the two graphs are extremely different from each other, with change in Galang having a higher correlation than change in Torompupu.

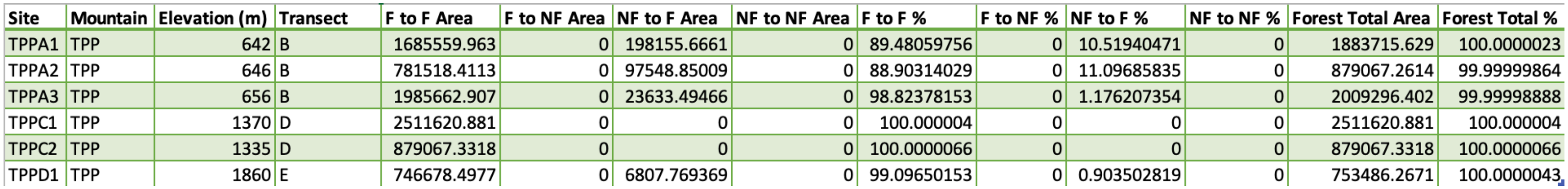
Table 1. Classification calculation for (a) Galang and (b) Torompupu.

(a)



Site	Mountain	Elevation (m)	Transect	F to F Area	F to NF Area	NF to F Area	NF to NF Area	F to F %	F to NF %	NF to F %	NF to NF %	Forest Total Area	Forest Total %
DKA1	GLG	338	A	558749.0887	1098131.842	167985.0632	310011.8009	26.1724172	51.4376941	7.86860372	14.52129113	726734.1519	34.04102091
DKA2	GLG	495	A	805345.7999	1189550.888	14400	0	40.0809811	59.2023534	0.7166687	0	819745.7999	40.79764977
DKB1	GLG	974	C	1211825.547	923052.0719	0	0	56.7632313	43.2367666	0	0	1211825.547	56.76323133
DKB2	GLG	992	C	911916.9875	469474.4114	0	0	66.01438	33.9856178	0	0	911916.9875	66.01437999
DKC1	GLG	1380	D	275411.0296	101332.1127	0	0	73.103135	26.8968717	0	0	275411.0296	73.103135
DKD1	GLG	1751	E	1506972.35	0	0	0	99.9999921	0	0	0	1506972.35	99.99999213
DKD2	GLG	1743	E	2134877.759	0	0	0	100.000005	0	0	0	2134877.759	100.0000045
DKE1	GLG	2238	F	2009296.739	0	0	0	100.000006	0	0	0	2009296.739	100.0000057
DKE2	GLG	2238	F	1883715.567	0	0	0	99.999999	0	0	0	1883715.567	99.99999901

(b)



Site	Mountain	Elevation (m)	Transect	F to F Area	F to NF Area	NF to F Area	NF to NF Area	F to F %	F to NF %	NF to F %	NF to NF %	Forest Total Area	Forest Total %
TPPA1	TPP	642	B	1685559.963	0	198155.6661	0	89.48059756	0	10.51940471	0	1883715.629	100.0000023
TPPA2	TPP	646	B	781518.4113	0	97548.85009	0	88.90314029	0	11.09685835	0	879067.2614	99.99999864
TPPA3	TPP	656	B	1985662.907	0	23633.49466	0	98.82378153	0	1.176207354	0	2009296.402	99.99998888
TPPC1	TPP	1370	D	2511620.881	0	0	0	100.000004	0	0	0	2511620.881	100.000004
TPPC2	TPP	1335	D	879067.3318	0	0	0	100.0000066	0	0	0	879067.3318	100.0000066
TPPD1	TPP	1860	E	746678.4977	0	6807.769369	0	99.09650153	0	0.903502819	0	753486.2671	100.0000043

Elevational community visualization

Within NMDS, the closest sites were the most similar to each other (Figure 7). The plotted species surrounding a site were the species that most affected the composition of the particular site, due to their abundance on the location. As seen in the figure, sites C and D were closest to each other. On the other hand, A was farthest from the rest of the sites. The second-farthest site from the group was F. The sites were also grouped by the mountain they are on.

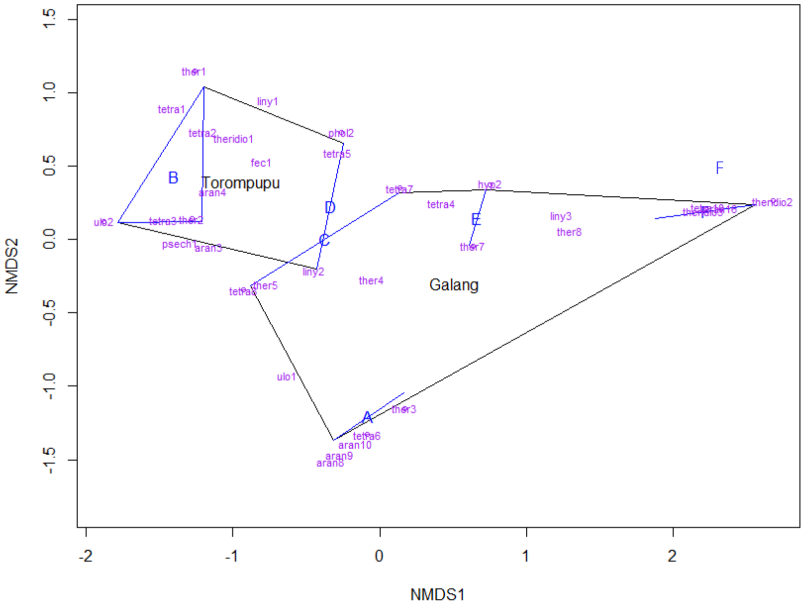


Figure 7. NMDS plot of elevational transects across Galang and Torompupu mountains. Sites that were closer together are more similar due to their species composition, which is also plotted. A was the farthest from the rest of the sites, so it is the most dissimilar.

Forest landscape and elevation effects on species composition

Within Galang, there was extremely low species diversity with a small amount of forest cover area (Figure 8). As the forest cover grew to approximately 800,000 square meters, species diversity also dramatically increased to just below 0.9. Then, the diversity fluctuated until it underwent a steep decrease around 1.8 million square meters of forest cover.

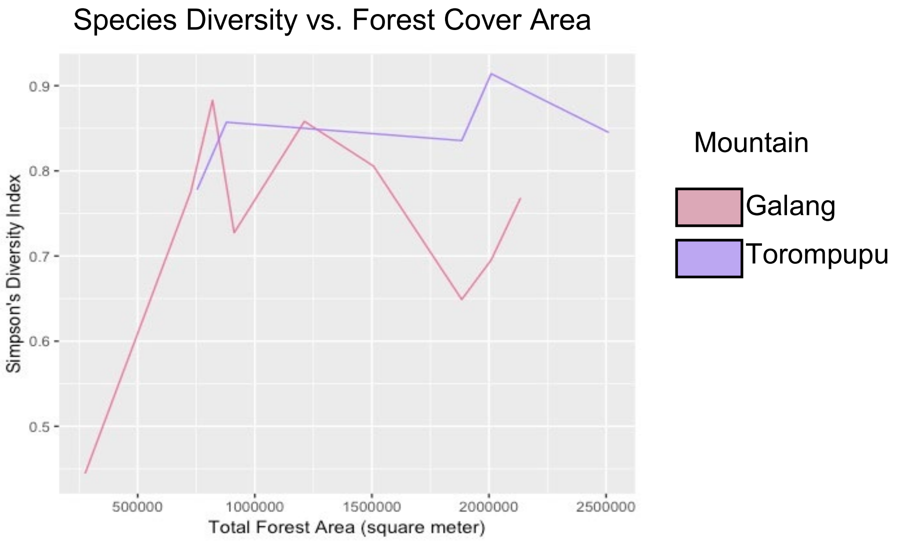


Figure 8. Simpson's diversity indices on Galang and Torompupu mountains across total forest cover area.

Within Torompupu, there was low species diversity at the lowest amount of forest cover (Figure 8). It increased and stabilized at approximately 800,000 square meters. Species diversity increased at approximately 1.8 million square meters of forest cover, then gradually decreased.

In comparing the forest cover across the two mountains, Torompupu had sites with higher forest cover area (Figure 8*)*. Overall, Torompupu also had the higher species diversity with lower variability in values in comparison to Galang (Figure 9).

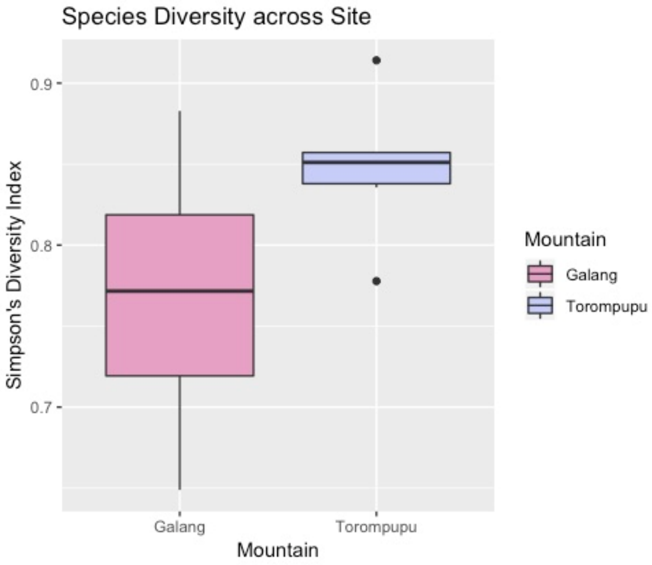


Figure 9. Comparison of Simpson's Diversity Index across the two mountains. Galang displays a longer boxplot due to a larger range of elevation accessible to be sampled on the mountain.

Throughout elevational transects, Simpson's species diversity index generally followed a hump-shaped pattern across elevation (Figure 10). The lowest species diversity occurred at the highest elevational site, F. The highest species diversity occurred at site B, with site D as a close second.

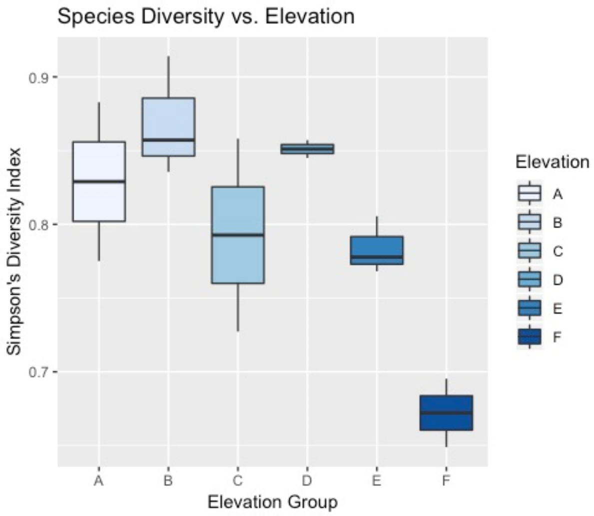


Figure 10. Simpson's diversity indices in Galang and Torompupu by elevational groups. The highest site, F, has the lowest diversity index by far.

Across the two mountains, there were only six species that overlapped (Figure 11). There was only one species that overlapped with site A and any other elevation group: Theriididae. Theriididae was also the only species that overlaps across every elevational group.

Figure 11. Six species that overlapped across Galang and Torompupu mountains, by elevational groups. The only species that overlaps with A and any other group is also the only species that overlaps across every elevational transect. It is part of the Theridiidae family.

Confirmation of results

After running the PERMANOVA with beta diversity indices as the response variable, I found that the F-values for both variables and their interaction effects are below the baseline of significance, 0.05 (Table 2a). I repeated these steps for the Bray-Curtis dissimilarity indices and also confirmed the significance of the variables and their interaction effects (Table 2b).

Table 2. PERMANOVA results with (a) Beta Diversity and (b) Bray-Curtis Dissimilarity as response variables. F-values for both factors and factors' interaction effects are significant (< 0.05) for both formulas.

Beta Diversity ~ Elevation (m) * F to NF % **(a)**

	R^2	F-value
Elevation	0.16	0.001
F to NF %	0.10	0.012
Interaction (Elevation: F to NF %)	0.10	0.013

Bray-Curtis dissimilarity ~ Elevation (m) * F to NF % **(b)**

	R^2	F-value
Elevation	0.16	0.001
F to NF %	0.11	0.021
Interaction (Elevation: F to NF %)	0.10	0.048

DISCUSSION

The differences in spider composition on sampled sites were significantly affected by elevational and forest cover change. I found that the highest amount of forest cover loss occurred on lower elevations and within Galang. The amount of forest coverage affected species diversity until elevational effects began to take place – although higher elevations of Galang had the largest amount of forest cover due to being most isolated, they also contained the lowest species diversity due to having harsher, less accessible environments. Both separate and interactional effects of environmental and anthropogenic factors influence the survival rate and dispersal patterns of species communities, so each component must be considered in future studies.

Forest cover loss

The magnitude of forest cover loss within Galang and Torompupu was influenced by the proximity to urbanized areas and accessibility of mountainous regions due to the steepness of their slopes. Within Galang, the highest amount of forest cover loss between 2015 and 2018 occurred on lower elevations, whereas none occurred at the sampled sites on Torompupu (Figure 5). Galang is a more urbanized area, with a major city only 30 minutes away from the mountain. Tolitoli is the capital city of a main regency in Central Sulawesi, so it is populated. On the other hand, Torompupu is located on a relatively isolated mountainous area with only a small village nearby. It is also located on a steeper incline, so the area is less accessible and populated by people compared to Galang overall (Holmquist 2019, unpublished). The change of non-forest to forest observed on Torompupu's lower elevations had too low of a correlation to be considered significant (Figure 6b). Therefore, the only clear conclusion from the comparison of the two mountains is that Torompupu was much less disturbed by anthropogenic activities than Galang. Although there have been recent legislation changes to reduce deforestation rates in Indonesia (Margono et al. 2012), other studies have also confirmed that certain areas, such as Central Sulawesi, are still losing forest landscapes (Rijal et al. 2019). As loss of forest cover on islands has a greater impact than on the mainland (Kier et al. 2009), Sulawesi's contribution to the global biodiversity can be detrimentally affected.

Forest cover and species community

Species diversity increased with forest cover until environmental effects associated with higher elevations became more influential predictors of species diversity. Although higher-elevation areas had more forest cover, they were also the least accessible with extreme environments, so fewer species are able to survive even with favorable forest surroundings. Within

Galang, species diversity was extremely low with small forest cover area, and the diversity increased with area up to a point (Figure 8); however, I observed an outlier as one of the lowest species diversity indices was displayed on sites with some of the highest amount of forest cover. This occurrence was observed on the higher elevational areas of Galang, which are isolated and contained a larger amount of undisturbed forests. Nonetheless, the inaccessibility of the region, harsher temperatures, and stronger wind can only support particular specialist species, which explains the low variety of species found on the sites (Foord and Dippenaar-Schoeman 2016). As a contrast, species diversity increased across the same amount of forest cover on Torompupu. Since Torompupu experienced less forest cover loss (Figure 5b, Figure 8), mid-elevational sites had comparable amounts of forest cover as high-elevational sites on Galang. Therefore, the species on Torompupu thrived with high forest coverage without experiencing the higher elevational effects as observed on Galang. Overall, Torompupu also had higher species diversity than Galang (Figure 9). Because of Torompupu's lack of human disturbance in comparison to Galang (Figure 5), the mountain's sites had a higher overlap of various species of spiders. In past studies, areas with primary forest cover are also found to have higher diversity than agricultural lands (Koneri and Nangoy 2006, Rodriguez-Artigas et al. 2016).

Elevation and species community

Species composition of spiders were more alike across sites with similar elevational ranges. Sites B, C, and D are grouped closer to each other, whereas the lowest and the highest elevational sites were the most different from the other sites (Figure 7). While other elevational groups had more than one species overlap with each other, site A only had one overlapping species (Figure 11), which explained its high dissimilarity of species composition with other locations (Figure 7). The species that overlapped with A was also the only species to overlap with every elevational group (Figure 11). The species is part of the Theridiidae family, which is one of the most diverse and common groups of spiders (Leong et al. 2017). In past studies, non-native species are found to have driven the species richness of lower elevations, due to the regions' accessibility (Haider et al. 2018). Therefore, the overlapping species was most likely to be a generalist species that was able to survive in many types of environmental conditions.

Across elevation, the trend in species diversity most closely follows a hump-shaped pattern, which is often found in other ecological studies. Despite experiencing the highest disturbance, site A had a relatively high species diversity index (Figure 10). Even with disturbances, lower sites are still the most accessible area compared to the other elevational ranges, allowing for a higher amount of non-native species to migrate and to settle on the islands (Haider et al. 2018). I observed the highest species diversity on mid-elevational sites, whereas the lowest diversity occurred at the highest elevational site (Figure 10). This trend is confirmed by most literature, since middle elevational areas tend to have a complex landscape with various habitats that can support a higher number of species (Foord and Dippenaar-Schoeman 2016, Lomolino 2001, Mittelbach et al. 2007). As mentioned, sites on higher altitudes have more extreme temperatures, harsher winds, and low connectivity (Rodriguez Artigas et al. 2016). The small accessibility and niche environment prohibit a large variance of species to survive in high elevations; however, with high forest cover, low disturbance, and less isolation, different kinds of spiders were able to thrive on mid-altitudes. The larger range of elevation Holmquist was able to sample on Galang compared to Torompupu also explained the higher variability found in Galang's range of diversity indices (Figure 9).

Environmental or anthropogenic effects?

The two mountains' species compositions were affected by both changes in elevation and forest cover. Between Galang and Torompupu, only six species overlapped across the two mountains out of a total of 58 species found (Figure 11). Since the two mountains represent fairly different habitats from each other, the environmental and anthropogenic factors that distinguish Galang and Torompupu played a critical role in the mountains' distinct species composition. To confirm findings, I ran PERMANOVA tests to affirm the validity of effects from elevational and forest cover change influencing beta diversity and Bray-Curtis dissimilarities, respectively (Anderson 2017) (Table 2). Although the somewhat low r^2 values appeared discouraging, a study evaluating ecological papers found the mean amount of variance reported to only be between 2.5 and 5.5% (Møller and Jennions 2002). Within ecological and evolutionary studies in particular, evaluated systems are complex, and most of the variance is connected to variables that are difficult to measure or to stochastic processes. Since the explanatory variables and their interaction effects were below the minimum baseline for significance (Table 2), the variance within the species composition that was accounted for by elevational change and forest cover is confirmed to be non-stochastic. Therefore, the elevational change and forest cover change had significant influences on the composition of spiders.

Limitations

Throughout the study, I experienced a few limitations particularly within the study design that may have reduced the accuracy of some findings. First, tropical forests are difficult to sample as there are many inaccessible areas; therefore, Holmquist was unable to sample lower and higher elevational sites on Torompupu. Doing so would have increased the robustness of the spider composition comparison between the two mountains. Secondly, Sulawesi is an extremely cloudy area. I found difficulty in finding Landsat 8 imageries for the two study sites that did not include much cloud coverage from the same season throughout the 2000's to the present. Therefore, I was unable to expand my time range to before 2015, as I originally planned. If I had more time to conduct the study, I also would have liked to include additional environmental factors to test if they help to explain species distribution patterns, such as temperature and slope, but I ran out of time. Lastly, part of the research question is to compare the species diversity over temporal land cover change, yet the spider samples were only from one time period. Attaining samples directly from the two time periods allows for more direct, accurate comparison of the changes in species composition.

Future directions

Based on findings, I would suggest studying the composition of spiders that make up elevational sites and their roles in detail. If spiders found on the same elevational groups generally have the same role, it reaffirms the effects of forest habitat on community survivability. For example, studying the web structures found on elevational sites would reaffirm the kinds of spider roles found on each elevation level. Furthermore, rather than utilizing QGIS and R, I would explore using Google Earth Engine to classify land cover change. It significantly reduces processing time and increases accuracy, since many of the Landsat imageries that can be imported within the tool are already pre-processed and cloud-masked. It can also be used to further narrow classifications into concessions, agriculture, and other specific classes. Lastly, I would factor in measurement of land connectivity in addition to the classification methodology. Studying the relationship between patches of habitat would supplement the evaluation of how spiders disperse across elevation.

Conclusion

In 2014, a comprehensive study found that Indonesia had surpassed the deforestation levels in Brazil, which had previously been the historical leader in forest cover loss (Margono et al. 2014). As my findings suggested, the mountain with a higher amount of forest cover had the higher overall species diversity. With habitat lost having a correlation to reducing biodiversity (Fahrig 2003), the protection of highly endemic islands particularly in Southeast Asia becomes more important with looming climate change effects, such as a higher frequency of forest fires. Just last year, wildfires from El Nino exacerbated a large proportion of forest cover in the country (Erickson-Davis 2019). Although the most recent account of deforestation rate in Indonesia has shown a decrease in recent years, it is still displaying an upward trend with worrisome negative implications (Global Forest Watch 2019). Since these islands contain a large proportion of the global biodiversity, conservation efforts should be maximized in areas with high species richness, especially if they experience disturbance. Although some of the lowest diversity occurred on the highest elevation sites within my observations, these sites are also most likely to contain a higher amount of endemic species, due to the theory of isolationism (Foord and Dippenaar-Schoeman 2016). However, the species composition of lower sites may also be more negatively affected by high levels of anthropogenic activities. A detailed evaluation of the interplay between disturbance level and endemism rate is necessary to determine regions of interest for concentrated conservation. Underlying environmental trends from historical underpinnings must be considered with as much weight as modern changes, as they both play dynamic roles in species distribution and survivability.

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