ASSESSING POTENTIAL PHENOLOGICAL SHIFTS IN RELATION TO WESTERN

CHIMPANZEE (*PAN TROGLODYTES VERUS*) HABITAT QUALITY


by


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A thesis submitted to the Graduate Council of
Texas State University in partial fulfillment
of the requirements for the degree of
Master of Arts
with a Major in Anthropology
May 2021


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**ABSTRACT**

The exact ways that climate change impacts primate reproduction and survival are still being understood and investigated. As foraging and nesting are two well documented and integral parts of primate survival, using feeding and nesting trees to understand climate change is a measurable way to infer changes in potential survival success. Looking at a chimpanzee (*Pan troglodytes verus*) community at Fongoli, Senegal, which already experiences heat stress and anthropogenic disturbance, how would climate change further impact habitat quality using feeding and nesting trees as an indicator? Previous research of the Fongoli chimpanzees shows that behavioral adaptations, including cave use and a shifted activity budget that focuses on more nocturnal movement, have allowed the chimpanzees to adjust to life in an extremely hot environment (Wessling et al. 2018). As chimpanzees are ripe fruit specialists and are impacted by fruit seasonality, how would fruit phenological stages be impacted by climate change? Using a longitudinal record of phenological data collected from 2006 to 2020 at the Fongoli, Senegal study site, I compared the availability of several phenology stages (e.g., fruit, leaves) over time. Incorporating variables such as the maximum, minimum and mean temperature in addition to mean precipitation, I addressed how phenological shifts, or the delay of phenological stages, might impact chimpanzee habitat quality. Based on Chi Square Test results, there were significant similarities between 2006 and 2020 for ripe fruit availability during the wet season; there was a significant similarity in new leaf availability between 2006 and 2020 during the dry season, and a significant association in flower availability between

2006 and 2010 during the dry season. For environmental data, a One Sample t Test was conducted for both precipitation and temperature; only 2007 deviated from the mean precipitation test value. Mean temperature yielded no statistically significant differences between years from 2006 to 2018, with the highest mean temperature being 31.98°C; maximum temperature yielded 2016 as being statistically different from the mean test score of 32.27°C, with no significant minimum temperature differences. The phenological and environmental data suggest that, while climate change is due to impact chimpanzee habitat quality, phenological shifts are not actively happening at Fongoli to the extent that the obtained data can show.

# I. INTRODUCTION

Climate change is anticipated to be one of the main causes for primate extinction in upcoming decades (Cowlishaw 1998). While a substantial amount of field research has included anthropogenic factors such as hunting, the pet trade and other explicitly human-driven endeavors, global climate change and its associated implications are just beginning to be studied at great length. This is partially due to the increasingly available data on the subject and the ease with which climatic data can be shared and analyzed, but also due to governmental organizations beginning to acknowledge the role large-scale human activities have on climatic change (Faghmous & Kumar 2014). Coupled with this emerging research is the acknowledgement that non-human primates are under stress from climate change and that behavioral plasticity in the face of climatic shifts has limits (Bernard & Marshall 2020). While non-human primates can respond to shifting environmental conditions through a combination of behavioral modifications, the plants that comprise the bulk of their diet must adapt through other means. As climate change is comprised of multiple environmental variables that include temperature and precipitation, the shifts in these variables impact the phenology, or life stages, of plants. Phenological shifts, or the delay of phenological stages, are not only dependent on atmospheric variables, but also on species specific attributes, including the optimal growth conditions of species (Hatfield & Prueger 2015).

To understand how phenological shifts might be limiting accessibility to food and nesting resources for Critically Endangered Western chimpanzees (*Pan troglodytes verus*), my research focused on how climate change, as measured via temperature and precipitation, may have influenced phenological events for these apes at the limits of their

species range in Africa. With climate change expected to drastically alter the ranging patterns and survivability of primate species in the near future, my research aims to understand how habitat quality due to climatic shifts can limit access to important resources for chimpanzees.

**Research Goals & Objectives**

The primary goals of this research are to understand if and how phenological shifts in feeding and nesting trees utilized by Western chimpanzees at Fongoli, Senegal are impacted by changing climate variables over the short term. Through assessing previously collected data in climate variables constituting temperature and precipitation, an overarching aim of my research is to understand current impacts due to climate shifts. Predicting future trends can inform primatologists and conservationists about the possibility of food availability and plant extinctions as well as potential associated behavioral changes of chimpanzees. These primary goals are addressed through the implementation of two research questions:

**Hypotheses**

1. Do temperature and precipitation changes in the Fongoli area influence phenological shifts, or the delay of phenological stages, during the 14-year period (2006-2020)?

$H_1$: Temperature and precipitation changes will correlate with phenological changes at Fongoli during the course of the study period (2006-2020).

$H_0$: There will be no correlation between the changes of precipitation and temperature and the changes in phenology at Fongoli.

2. Do the trees used for feeding and nesting behaviors of Western chimpanzees exhibit phenological shifts during the 14-year (2006-2020) study period?

$H_1$: Phenological patterns statistically vary over the course of the study period.

$H_0$: There is no statistical variation in the phenological patterns during the study period.


3. Is habitat composition through Geographic Information Systems (GIS) at Fongoli detectible between seasons and years?

$H_1$: There are visible differences in habitat composition between seasons and years at

Fongoli.

$H_0$: There is no visible difference in habitat composition between seasons and years at

Fongoli.

## II. BACKGROUND

**Western Chimpanzees (*Pan troglodytes verus*)**

The Western chimpanzee is the most northern and westerly distributed of the chimpanzee subspecies, inhabiting the countries of Senegal, Mali, Liberia, Côte d'Ivoire, Sierra Leone, Guinea and Guinea Bissau (Kormos & Boesch 2003). They have recently become extinct in The Gambia, Benin, Burkina Faso and Togo (Kormos & Boesch 2003). The habitat composition of the Western chimpanzee ranges from savanna-mosaic environment in Senegal and Mali to more forested areas, including rainforest, in Liberia, Sierra Leone, Guinea, Guinea Bissau and Cote d'Ivoire (Wessling et al. 2020). As with other species of primate, Western chimpanzees also utilize anthropogenic, or human altered, land such as crop fields and roads (Bryson-Morrison et al. 2017).

In Senegal, most of the chimpanzee population lives outside of national protected areas (Ndiaye et al. 2017). Due to extreme temperatures, along with water scarcity, the chimpanzees at the Fongoli site in Senegal exhibit unique behaviors not seen in other chimpanzee groups, including soaking in small pools of water (Pruetz & Bertolani 2009), resting in caves (Pruetz 2007), and exhibiting more nocturnal behavior than chimpanzees elsewhere (Pruetz 2018). The Senegalese populations of Western chimpanzees also occupy the northernmost distribution of all chimpanzee subspecies (Wessling et al. 2020).

Traditionally, the difference in behaviors between forest and savanna chimpanzees is attributed to the environment in which each respective species has lived and evolved (van Leeuwen et al, 2020). However, this distinction of habitat is not a pure dichotomy, as many of the areas in which 'savanna' chimpanzees reside can be categorized as 'forested', such as in Cotê d'Ivoire and Liberia (Wessling et al. 2020). 'Savanna'

chimpanzees predominantly reside in hotter and drier environments, which yield higher degrees of competition for resources, such as access to water and food (van Leeuwen, 2020). In Senegal, chimpanzees live in a semi-arid biome, which is a hotter and drier environment than chimpanzees living in savanna landscapes elsewhere (Pruetz, pers. comm.).

**Chimpanzee Nesting Behavior**

As with other subspecies of chimpanzee, Western chimpanzees exhibit both day- and nighttime nesting behavior. Nesting has anti-predator benefits, as chimpanzees arboreally create nighttime nests to potentially avoid terrestrial predators, such as leopards (Pruetz et al. 2008). As noted by Pruetz and colleagues (2008), chimpanzee nesting height differs between areas with greater amounts of potential predation. Aside from anti-predation, ground nesting is occasionally exhibited in chimpanzee subspecies in addition to all other species of extant great apes; this behavior is a combination of multiple potential factors including restricted access to suitable nesting trees (Tagg et al. 2013). Chimpanzees in Senegal display possible preferences for nesting material, with *Pterocarpus erinaceus*, *Diospyros mespiliformis*, and *Anogeissus leiocorpus* comprising 60% of night nests, according to a 2015 survey across the country (Ndiaye et al. 2017). However, as noted by Ndiaye and colleagues, nests are subject to rapid decay during the wet season, therefore possibly biasing results of nest-tree species composition (Ndiaye at al. 2017). Chimpanzees at Fongoli specifically exhibit a sex bias toward nest building; females and immature males nest higher and in larger trees, with females additionally investing more time in nest construction (Stewart & Pruetz 2020).

**Chimpanzee Diet**

In regard to diet, Western chimpanzees are frugivore specialists but supplement their diet with meat, including galagos (*Galago senegalensis*), patas monkeys (*Chlorocebus aethiops*), baboons (*Papio hamadryas papio*), and other small prey (Lindshield 2014). The majority of their diet, approximately 60%, is comprised of fruit (Pruetz 2006). Western chimpanzees have adapted to fruit scarcity by adjusting their ranging patterns more widely or by utilizing fall-back food sources (Wessling et al. 2020). Data collected by Pruetz (2006) from feeding observations, partially consumed fruits, and fecal samples reveal Fongoli chimpanzees specifically eat 35 species of fruit bearing trees, with 71 tree species being consumed overall (FSCP, unpublished data).

**Anthropogenic Disturbance in Southeastern Senegal**

Anthropogenic disturbance, or the change that humans cause to an area or environment, has been documented thoroughly in the primatology literature as early as the 1980s (Riley 2013). With climatic change, resource over-extraction and population expansion, anthropogenic disturbance and the introduction of people into once 'pristine' environments is increasing steadily (Riley 2013). However, with a growing knowledge of the ways humans impact and modify their environment, there are the increasing efforts of disturbance off-set plans; these plans aim to allow non-human primates to continue to utilize their environment while allowing humans to remain in the area and continue their way of life (Toro Gold Ltd 2018[1]). In Senegal, the gold mining industry has been a driving factor in the modification of the environment and extraction of resources to some degree historically, but more significantly in recent years (Boyer Ontl 2017). Two of the

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[1] https://www.rml.com.au/wp-content/uploads/2019/11/2018-Sustainability-Report.pdf

main natural resources affected by gold mining, ground water and timber, are directly utilized by Western chimpanzees (Lindshield et al. 2019). Indirectly, incoming humans who rely on gold mining as a source of profit add strain to the area's infrastructure. This strain can lead to waste accumulation, the introduction of waste material into the environment and even introduction of diseases to chimpanzee communities (Ndiaye et al. 2017). While gold mining is a strain on the environment, it is ASGM that poses the largest threat to ecosystem harm, as there are an overall lack of guidelines set in place to prevent water contamination (Boyer Ontl 2017).

Additionally, non-timber resources such as *Saba senegalensis*, a dietary staple of Western chimpanzees, are a direct source of competition between chimpanzees and people in southeastern Senegal (Waller & Pruetz 2016). If economic dependence on *Saba senegalensis* increases, the harvesting of *Saba* is expected to expand past previously documented areas into new areas that overlap with chimpanzee home ranges. As stated by Knutsen (2003), *Saba* was initially harvested primarily by women and young children; however, due to economic desire, men began to harvest *Saba* and expand the harvesting range. Adding to these factors associated with human occupation, most chimpanzees in West Africa reside outside of traditionally protected areas like national parks or sanctuaries (Duvall 2008). Due to this, the efforts to protect them are largely contingent on community outreach, incentives to reduce the consumption of non-human primate meat, if applicable, and monitoring of chimpanzee populations on a routine basis (Binczik et al. 2017). In addition to the ecosystem level changes associated with anthropogenic activity, human-caused climate change is expected to increase global temperatures by as much as

1.5C° in coming centuries (Pearse et al. 2017).

**Small-Scale Artisanal Gold Mining**

One of the most prominent anthropogenic threats to Western chimpanzee habitat quality, **s**mall-scale artisanal gold mining, from now on referred to as ASGM, has historically been a prominent part of West African economies and a prominent part of its history (Wilson et al. 2015). As an extractive industry, ASGM puts stress not only on the geology of the area but also water resources through contamination and timber resources through harvesting (Ndiaye et al. 2017). In the West African country of Senegal, gold mining has likely occurred as early as 300 CE, according to established trade routes (Gewald 2010). In the Kedougou region of Senegal, an increase in traditional levels of gold mining occurred as early as 2008 in 70% of surrounding villages and increased in subsequent decades (Boyer Ontl 2017). This increase in ASGM leads not only to an increased pressure on the environment but also a population increase as a result of an influx of mining workers to the area (Ndiaye et al. 2017). This population boom can have detrimental affects to water quality and hygiene, with the sewage systems of the ASGM sites being largely nonexistent. Additionally, mercury used in ASGM can leak into ground water and contaminate water used by both humans and wildlife (Boyer Ontl 2017). Outside of anthropogenic change, an influx of people into areas of gold mining also brings a higher potential for bushmeat consumption and illegal wildlife trading as those outside of Senegal do not hold the taboos against eating chimpanzee meat (Ndiaye et al. 2017).

**Climate Change**

Climate change is an increasingly important factor for the survival of primate species and their habitats (Graham, Matthews & Turner 2016). Thermo-regulation of Senegal chimpanzees has been researched, as they inhabit portions of Africa with temperatures well over 37.7°C (Pruetz 2007; Wackerly 2019). Due to increasing heat stresses, water is a limiting resource in savanna environments with regards to the ranging patterns of chimpanzees (Wessling et al. 2020). Additionally, shifting activity budgets due to higher temperatures mean Fongoli chimpanzees are more active during nighttime (Pruetz 2018). With shifting climates, the distribution and preferred habitats of primate populations are also expected to shift (Korstjens, Slater & Hankinson 2018). In addition to shifts in general habitat, temperature is the major abiotic factor that contributes to phenological shifts (Scranton & Amarasekare 2017). However, in an arid to semi-arid environment, precipitation, rather than temperature, is the limiting factor for plant growth and development, second only to photoperiod (Yan et al. 2015). In regards to precipitation, steady amounts of rain are optimal for plant growth and development as opposed to intensive and infrequent precipitation events, such as massive flooding (Lesica & Kittelson 2010). Rainfall patterns observed in the Sahel, which includes northern Senegal, also favor the production and long-term biomass expansion of woody plants rather than herbaceous plants (Brandt et al. 2019). While there are short-term increases in herbaceous biomass periodically, woody plants have a greater likelihood to grow and continue to produce rather than periodically lose biomass. During the 1970s and 1980s, precipitation was the driver for primary biomass production after a prolonged drought period (Brandt et al.

2019).

**Phenology**

  Phenology, or the understanding of life cycles and life history events in organisms, has important implications for understanding climate change and shifting seasonal on-sets (Scranton & Amarasekare 2017). Phenology utilizes the understanding of varying life stages and their duration to assess how these life stages potentially change, each life stage's timeframe, and how the environment impacts phenology (Scranton & Amarasekare 2017). While photoperiod is the main driving factor for plant growth, plants specifically react to changes in temperature through a variety of adaptive measures, including enzyme inactivation, reaction kinetics and hormonal regulation. In sub-Sahelian Africa, the understanding of phenological dependence on environmental input is limited, and the fluctuation of phenological stages is uncertain (Adole et al. 2019). Phenology is also important for understanding annual and seasonal fluctuations of biomass production, especially fruit in regards to great ape diet (Kagoro-Rugunda & Hashimoto 2015). As chimpanzees are described as ripe fruit specialists, and a large portion of their diet is fruit based, the changing phenological timelines of specific fruit trees can inform and possibly predict chimpanzee foraging adaptability (Janmaat, Ban & Boesch 2013). The key to understanding these relationships is knowing the optimal temperatures that specific plant species carry out specific processes including pollination, fruiting, and leaf production. Climatic changes, specifically in precipitation, has been shown to impact seed germination, seedling growth and phenology overall (Yan et al. 2015).

## III. METHODS

**Study Site**

Research was conducted at the Fongoli Savanna Chimpanzee Project site, located within the Department of Kedougou in Senegal. Established by Dr. Jill D. Pruetz in 2001, the study site is 10km NE from the town of Kedougou and 45km SE from Niokolo-Koba National Park (Pruetz 2006). The site is classified as a savanna-mosaic environment with grassland and woodland making up the predominant area of the Fongoli chimpanzees' home range (Pruetz & Bertolani, 2009). The year is differentiated by wet and dry seasons, with a longer dry season (from November to May) and a shorter wet season (June to October). Depending on yearly rainfall timing, May and October can be considered transitional months. Virtually no rain falls between late November and mid-May. The average rainfall per year at Fongoli is approximately <1000 mm but has become more erratic and inconsistent in recent years (Pruetz & Herzog 2017). Maximum temperatures at Fongoli exceed 40°C in the dry season, with lower temperatures during the wet season reaching 25°C (Pruetz & Bertolani 2009). The Fongoli chimpanzee group averages approximately 32 individuals (n=15 years), with a higher number of males than females (10-12 males, 7-8 females annually) (FSCP, unpublished data). The home range of the Fongoli chimpanzees is approximately 90km$^2$ (Pruetz & Herzog 2017). Male chimpanzee subjects are prioritized to decrease the risk of over habituation of females to non-researchers (FSCP, unpublished protocol). Such habitation can lead to an increase in poaching, of which there has been one documented case at Fongoli (Pruetz & Kante 2010). Adult

males are targeted for focal subject follows, with an individual male being selected randomly each day to be followed from night nest to night nest. If a male is lost, then the next male on the list is selected to be followed (FSCP, unpublished protocol).

Due to the COVID-19 global pandemic, field study by international researchers at Fongoli was cancelled during 2020. Data for this study was instead obtained from the Fongoli Savanna Chimpanzee Project database with the permission of Dr. Pruetz and contributing researchers. Data collected included monthly records from the phenology transect, established by Dr. Pruetz and field assistants, in addition to climate data on temperature and precipitation.

**Precipitation Data**

Precipitation data was obtained primarily from the FSCP for the years of 2006 to 2018. To provide a larger window to assess possible legacy effects of precipitation on woody plant species, precipitation data from 1990 until 2006 was obtained from the National Oceanic and Atmospheric Administration (NOAA) dataset of 'Global Monthly Summary' data. These data were collected from ground weather stations positioned in Tambacounda and Kedougou. Kedougou is located 15km from Fongoli camp and less than five kilometers from the southeastern edge of the Fongoli chimpanzees' range, while Tambacounda is located 233.9km from Kedougou. Such a wide temporal range was used since woody plant species are subject to more legacy effects of precipitation, while herbaceous plants are limited more by the precipitation of the current year (Brandt et al. 2019). Precipitation monthly average was used as the key ecological variable since a relatively constant amount of precipitation is more beneficial for plant growth than intense but infrequent precipitation events (Li et al. 2019). Additionally, repeated heavy precipitation

events are more detrimental to total biomass than infrequent flooding events. Mean yearly precipitation was also used, as during the dry season little to no rainfall occurs, making the distinction between maximum and minimum precipitation indistinguishable during this time frame, which includes several months of the year.

**Temperature Data**

Temperature data was collected through the National Oceanic and Atmospheric Administration (NOAA) global database from the 'Record of Climatological Observations'. This database consists of monthly breakdowns of mean temperature in degrees Fahrenheit for 2006 to 2018 from land-based weather stations in Kedougou and Tambacounda. Mean yearly temperature was used as, while maximum and minimum temperatures create a window of optimality, mean temperature combined with precipitation limitations are what drives phenological onsets in savanna vegetation (Workie & Debella 2018). However, while mean temperature is important for overall production of biomass, changes in temperature have effects for specific phenological stage onsets; Hatfield and Prueger (2015) note that pollen production is the most susceptible to temperature shifts, which may affect fruit-bearing trees the most.

**Phenological Data**

Phenology data used in this study was collected at Fongoli from 2006 to 2020, along a transect comprised of approximately 700 trees. The phenological transect is 3.2km and 10m wide. Phenological data is collected in the middle of each respective month, usually either the 15th or the 16th. Criteria was based on an individual tree having a diameter at breast height (DBH) of >10cm. Additionally, species important to Fongoli chimpanzee diet were sought out and tagged if they were represented by fewer than 10

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individuals on the transect (e.g., *Cola cordifolia*). Each tree is marked with a tree tag, denoting a number assigned to the individual. The Malinke name of the tree is documented as well as the scientific genus and species if known.

**Normalized Difference Vegetation Index (NDVI)**

Normalized Difference Vegetation Index, from now on referred to as NDVI, utilizes reflected light rays to visually display the expected density of vegetation. Density is on a continuum of -1 to 1, with 1 representing dense vegetation, such as jungle, while -1 represents a lack of vegetation (Rhew et al. 2011). Commonly used in forestry and agricultural pursuits, NDVI provides a metric for the assessment of foliage density across a spatial matrix.

Limitations of NDVI are the lack of specific habitat attribution in the context of Fongoli. While a scale of -1 to 1 can inform the density of vegetation, it does not inform on specific habitat type or exact foliage composition. An additional limitation is the soil surface reflectance at the low vegetation end of the NDVI spectrum, which does not account for low amounts of vegetation in comparison to open areas of soil (Karnieli et al. 2009). As atmospheric correction is required to provide NDVI results, Landsat 8 OLI/TIRS CS L2 was obtained to automatically incorporated corrected map layers.

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**IV. ANALYSIS**

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**Global Information Systems (GIS)**

To contextualize phenological findings, Geographic Information Systems (GIS) maps were created of the Fongoli site in Senegal. As Landsat 8 data was not available for 2006, data was obtained from both wet and dry seasons of 2016 and 2020: February 16th and November 21, 2016 and February 18th and November 16th, 2020. Landsat 8 OLI/TRI C1 L2 On-Demand data sets were downloaded and corrected for surface reflectance in accordance with USGS guidelines.

GIS analysis consisted of running a Normalized Difference Vegetation Index (NDVI) function. A shape file of the Fongoli chimpanzee home range obtained from Boyer Ontl (2017) was added to provide physical parameters. GPS points of gold mining sites were added to show the possible extent of anthropogenic disturbance in conjunction with NDVI changes. As no statistical analyses were performed for the GIS maps, the use of GIS maps is solely for descriptive comparisons across years and seasons rather than statistical analysis.

**Statistical Package for the Social Sciences (SPSS)**

Table 1 contains the independent and dependent variables for each statistical procedure. Phenological categories assessed include presence/absence of new leaves, mature leaves, flowers, buds, and fruits (ripe, unripe, and present). Temperature was measured in degrees Celsius (C), and precipitation was measured using millimeters (mm).

**Table 1. Independent & Dependent Variables for Statistical Analysis**

| | Independent Variable(s) | Dependent Variable(s) |
|---|---|---|
| Temperature | | |
| **One Sample T Test** | Year | Temperature (°C) |
| Precipitation | | |
| **One Sample T Test** | Year | Rainfall (mm) |
| Phenology | | |
| **Chi Square Test of Association** | Temperature/Precipitation | Phenological category (leaves/flowers/fruit) |

**Phenological Data Statistical Analysis**

Phenological data were analyzed with SPSS software licensed to Texas State University. Phenological data at Fongoli was collected according to two differing categorizing systems between 2006 and 2020, depending on the specific questions addressed at the time. From 2006 to 2007 (Phase One), the system is a percentage estimation using parameters from 0 to 100, and data were collected by botanical researchers. For data collected from 2018 to 2020 (Phase Two), a four-stage categorization scheme was used following more extensive botanical training of researchers on site, based on the percentage of fruiting crown covered; for example, a '1' is comparatively less than a '4'.

To standardize phenological data between years, variables were recoded in SPSS to establish consistency. For data collected in Phase One (2006-2007), 1-25 was recoded to '1', 26-50 recoded to '2', 51-75 recoded to '3' and 76-100 recoded as '4' to match Phase Two (2018-2020) phenological categorization. In the case of 0, all accounts of 0 were kept consistent. All missing data was kept as 'missing' within SPSS. Table 2 contains the two phases and associated years within them. To account for seasonality within the annual data collected, 'wet' and 'dry' series were created with available data months. 'Dry' season series was comprised of  November of 2006 (Phase One), February/March/April of 2007 (Phase One) and February/March of 2019 (Phase Two). 'Wet'

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season series was composed of August, September and October of 2006 (Phase One), with August, September and October of 2020 (Phase Two). Table 2 contains the months

**Table 2. Phenological Data Strings for Statistical Analysis**

|  | **2006** | **2007** | **2018** | **2019** | **2020** |  |
|---|---|---|---|---|---|---|
|  |  | January |  | January |  | Dry |
|  |  | February |  | February |  | Wet |
|  |  | March |  | March |  |  |
|  |  | April |  |  |  |  |
|  |  | May |  |  |  |  |
|  |  | June |  |  | June |  |
|  |  | July |  |  | July |  |
|  | August |  |  |  | August |  |
|  | September |  |  |  | September |  |
|  | October |  |  |  | October |  |
|  | November |  |  |  |  |  |
|  | December |  | December |  |  |  |

and years used for the data 'series'; green represents 'dry' series while red represents 'wet' series.

A Chi-Square Test of Association was performed on phenological data from the beginning of the study, Phase One (2006), and the end of the study, Phase Two (2020), to assess any significant changes in new leaf production, fruit availability and presence or absence of flower buds over this 14-year period. For each dependent variable, a Chi-

Square Test of Association was performed for both 'wet' and 'dry' series between Phase One and Phase Two.

There was a significant association between the availability of ripe fruits between Phase One (2006) (N=178) and Phase Two (2020) (N=812) during the Wet series (x2 [N=174, df=2]= 12.526, p=.002. The differing frequencies of data between Phase One and Phase Two across variables are due to the ongoing establishing of the phenological transect at Fongoli over the course of data collecting during the 2006-2007 field season. The Dry series had a significant association between ripe fruit availability between Phase One (2006) (N=201) and Phase Two (2020) (N=767) (x2[N=395, df=12]=21.636, p=.042).
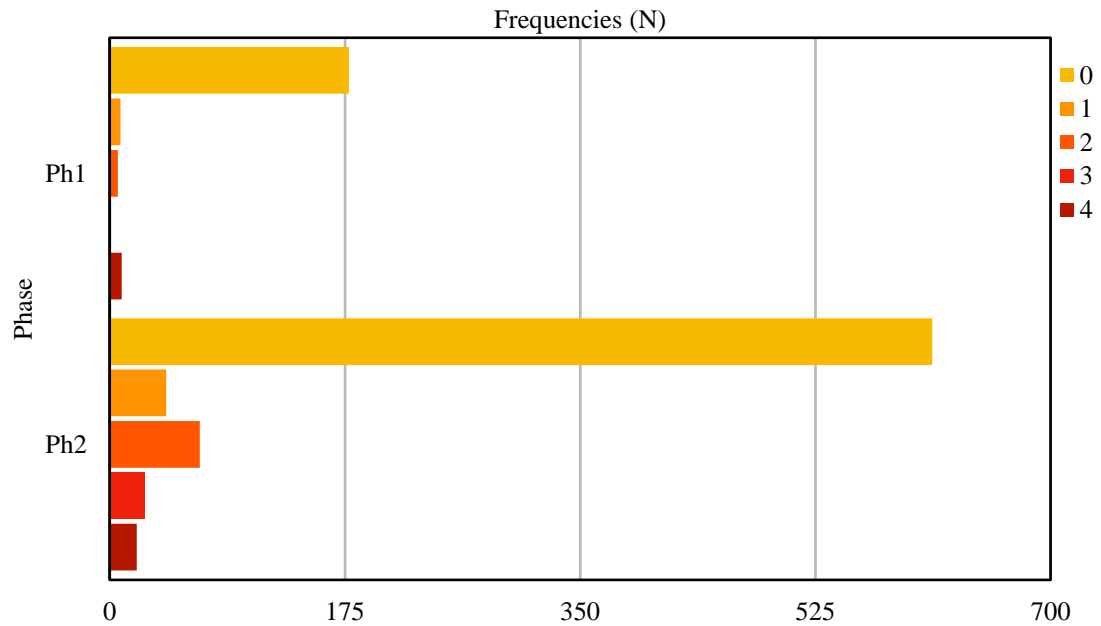


**Figure 1. Availability of Ripe Fruit at Fongoli, Senegal (Dry Series)**

Analyses of the availability of new leaves revealed a significant association be-

tween the availability of new leaves in Phase One (2006) (N=387) and Phase Two (2020)
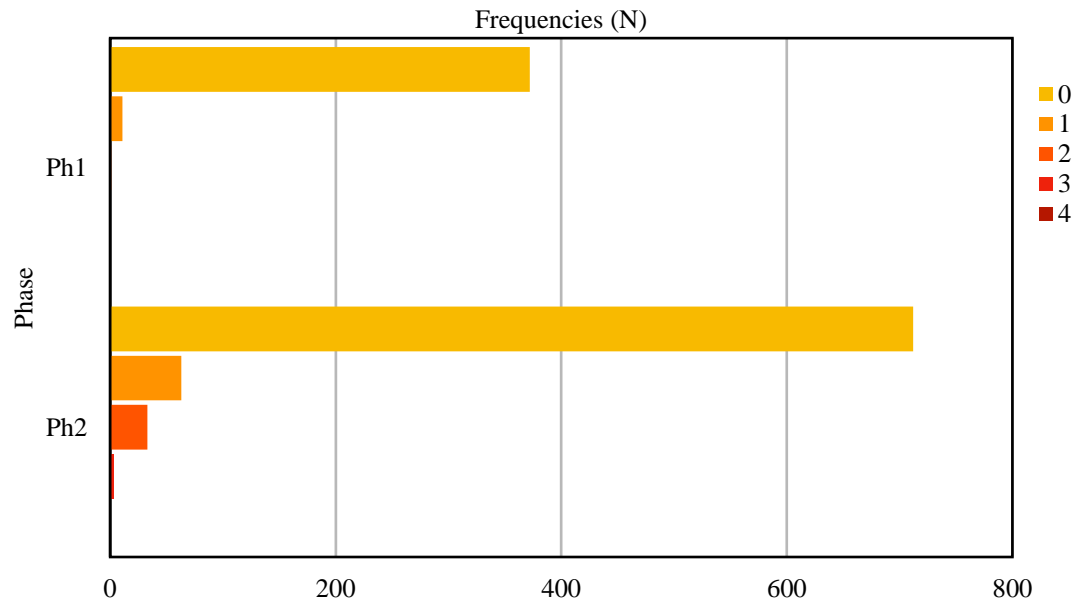


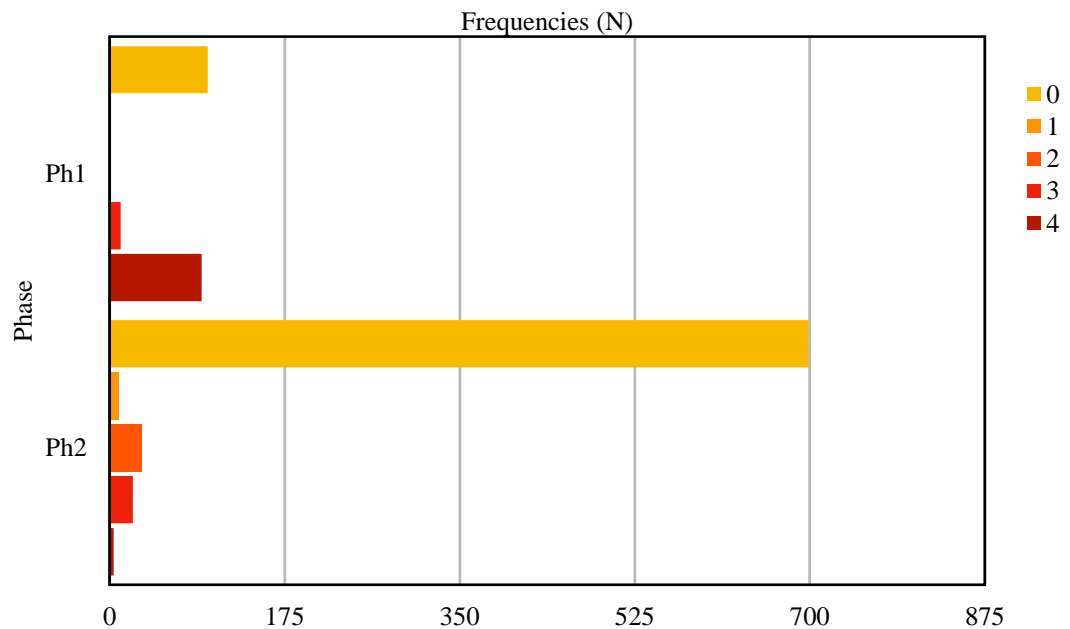**Figure 2. Availability of Ripe Fruit at Fongoli, Senegal (Wet Series)**



**Figure 3. Availability of New Leaves at Fongoli, Senegal (Dry Series)**

(N=813) for 'Dry' series ($x^2$ = [N=387, df=9]=18.517, p=0.030). 'Wet' series data between Phase One (2006) (N=174) and Phase Two (2020) (N=812) yielded no significant results using a Chi Square Test of Association ($x^2$ = [N=174, df=7]=4.835, p=0.680).

Assessing the availability of flowering buds between Phase One (2006) (N=198) and Phase Two (2020) (N=766), a Chi-Square Test of Association showed no significant association for the 'Dry' series, ($x^2$ = [N=191, df=10]=.258, p=1.000). For 'Wet' series between Phase 1 (2006) (N=174) and Phase Two (2020) (N=812), there was no significant association between the availability of flowers ($x^2$ = [N=154, df=3]=.159, p=0.984).

**Temperature & Precipitation Statistical Analysis**

A One Sample t Test was performed on temperature data between 2006 and 2018 for each year against the test value of 29.6°C. The test value of 29.6°C was used as the comparison as it was the mean temperature across all the years observed. Mean temperature, in addition to maximum and minimum yearly average temperatures, were used to assess if there were potential differences in optimality windows for plant growth; while mean precipitation is beneficial for plant growth, a window of temperature is more beneficial for plant growth than a consistent temperature. There were no statistically significant differences between the test value and the mean monthly temperature recorded for each year. The largest difference from the test value washigher by 4.27°C (95% CI, 12.30 to 3.75) from 29.6°C (t(3)=1.694, p=0.189). The lowest differencewas 2.60°C lower than (95% CI, 10.528 to 15.728) the test value of 29.6°C (t(2)=-.852, p=0.484).
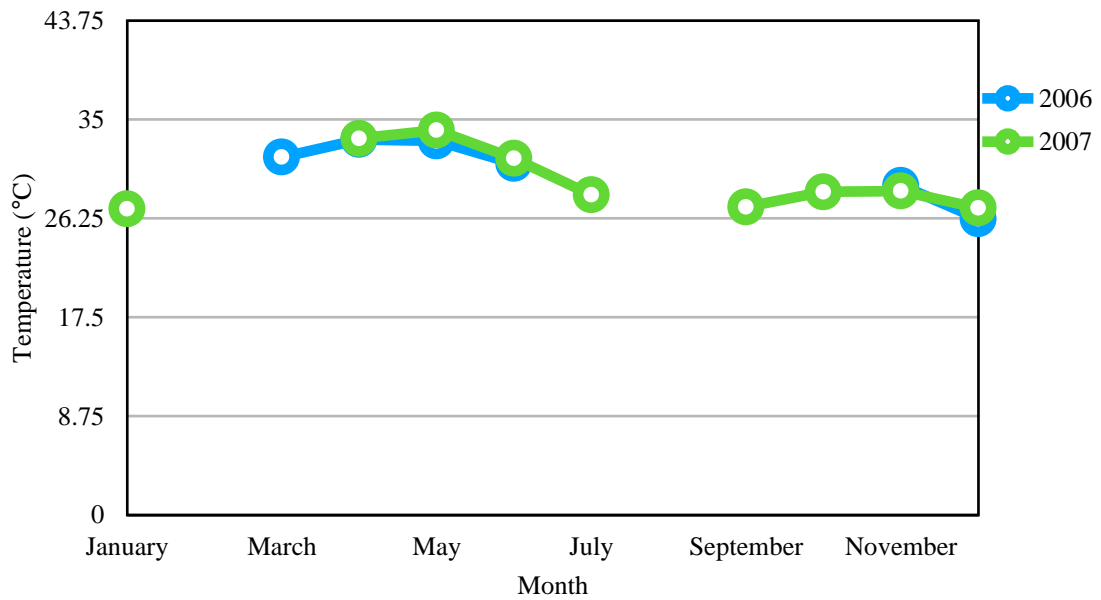
**Figure 4. Mean Temperature (2006-2007)**
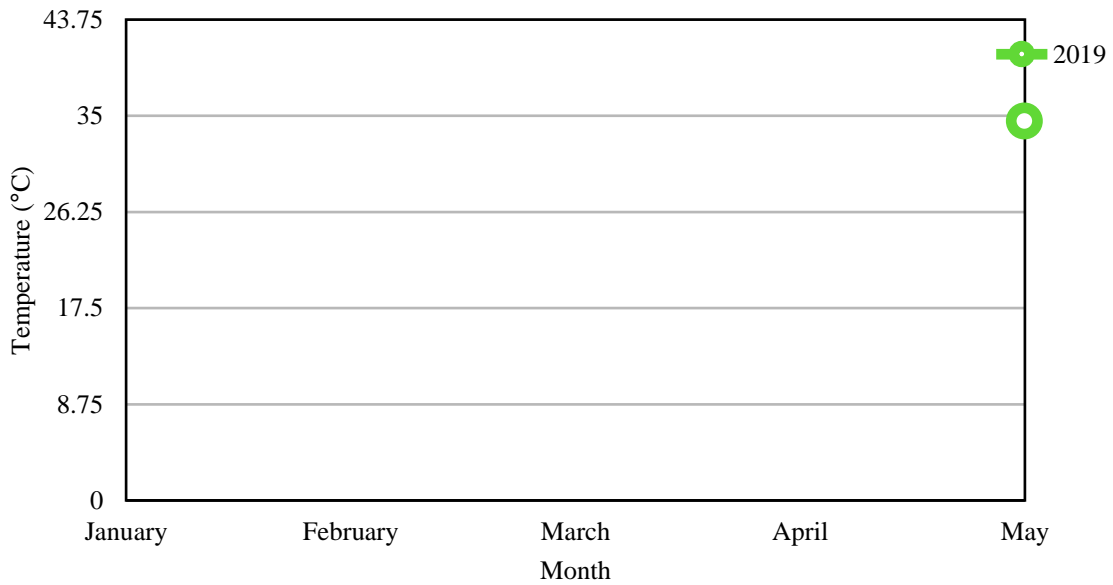


**Figure 5. Mean Temperature (2018-2020)**

In addition to mean temperature, maximum and minimum temperatures were also analyzed using a One Sample t Test for deviation from the test value. For maximum temperature, the only significant outlying year was 2016 (t(2)=-3.864, p=0.031 compared to

the test value of 37.27°C; when compared to 37.27°C, the maximum temperature of 2016 was 2.06°C lower.



**Figure 6. Maximum Temperature (2006-2007)**



**Figure 7. Maximum Temperature (2018-2020)**

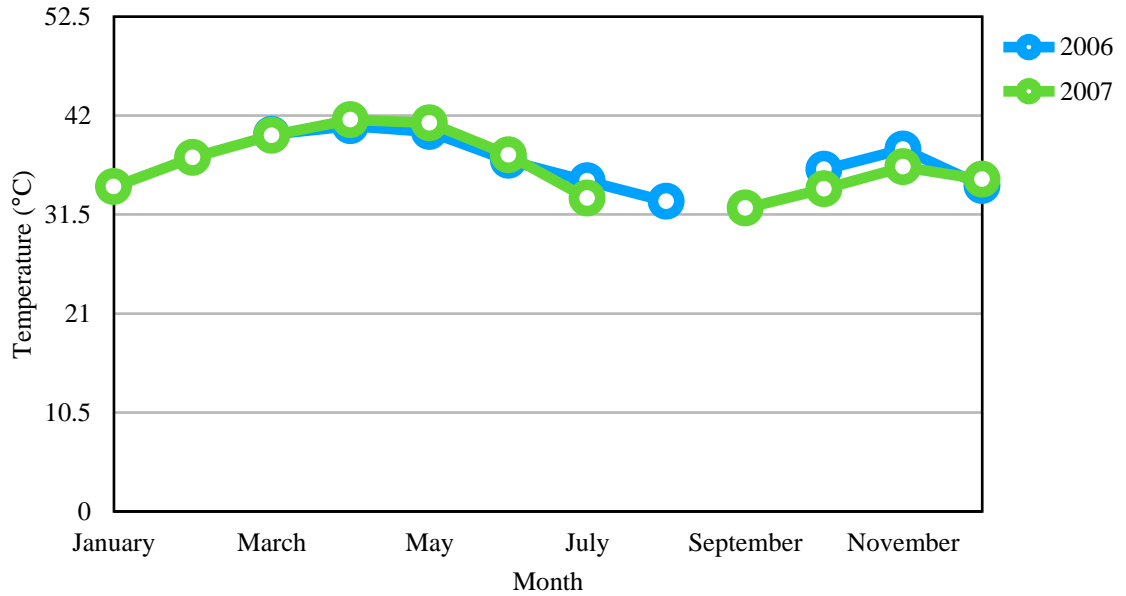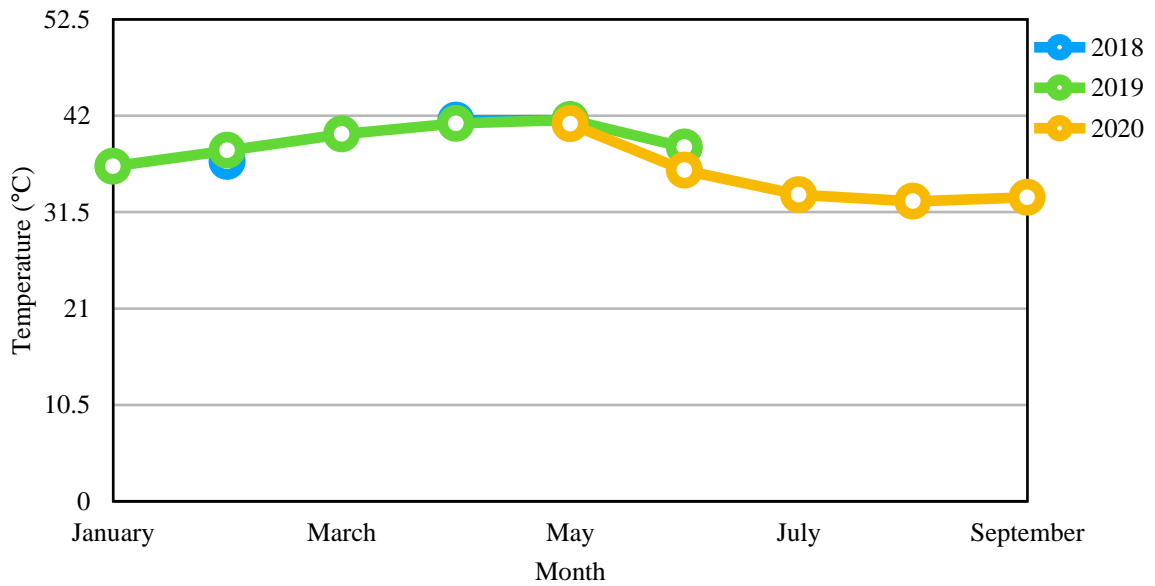For minimum temperature, there were no outlying years when compared to the minimum test value of 22.56°C. The largest difference from the test value of 22.56°C, in
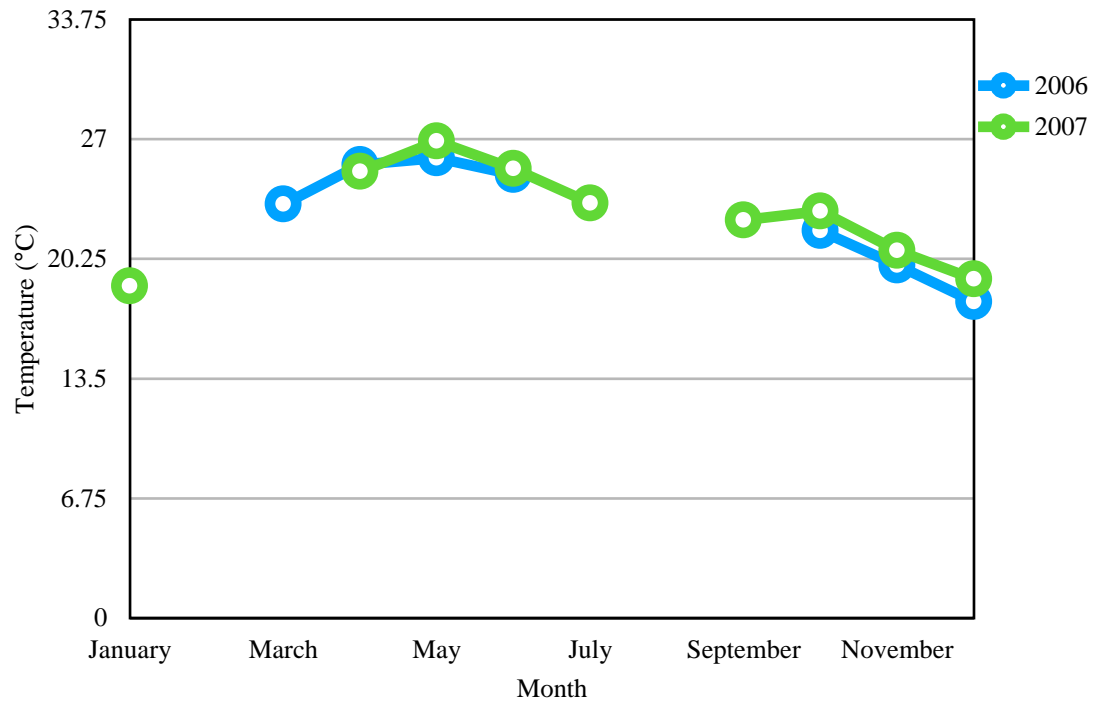


**Figure 8. Minimum Temperature (2006-2007)**
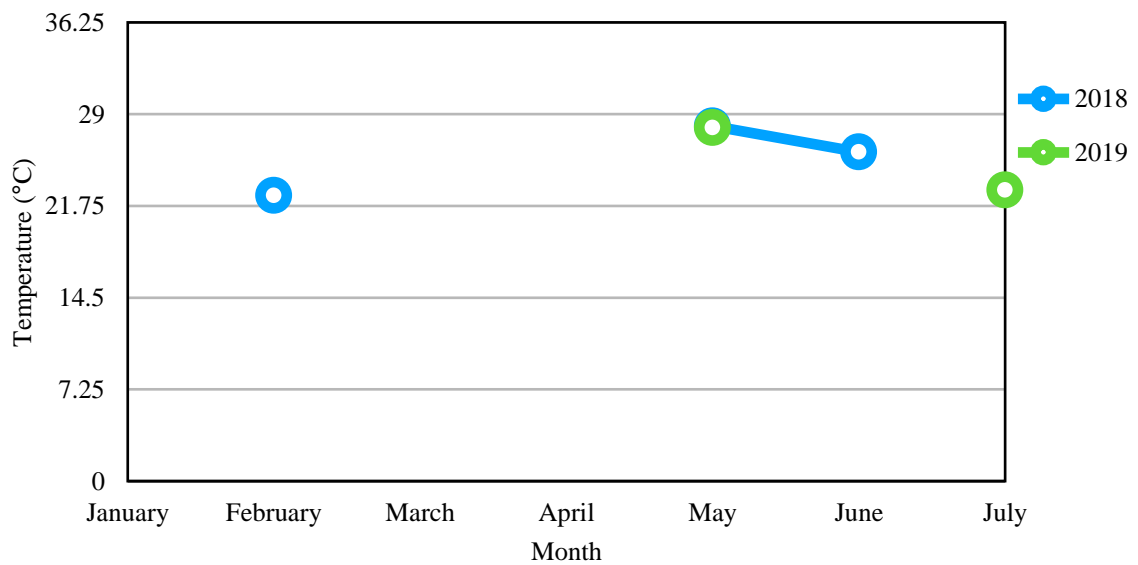


**Figure 9. Minimum Temperature (2018-2020)**

2019, was 2.91°C higher (95% CI, -28.47 to 34.29) (t(1)=1.178, p=.448). The smallest

difference from the test value of 22.56°C was in 2007, which was lower by .18°C (95%

CI, -1.98 to 2.35) (t(8)=.197, p=.849.

For mean precipitation, a One Sample t Test was conducted for each year of pre-

cipitation data, 2006 and 2018 (N=13). The test value of 82.4mm was used for the com-

parison as it was the average precipitation value across all years of obtained data. Across

individual years, the only years with statistically significant differences from the test

value was 2007. Rainfall in 2007 was lower by 48.52mm (95% CI, 10.90 to



**Figure 10. Mean Precipitation at Fongoli, Senegal (2006-2010)**
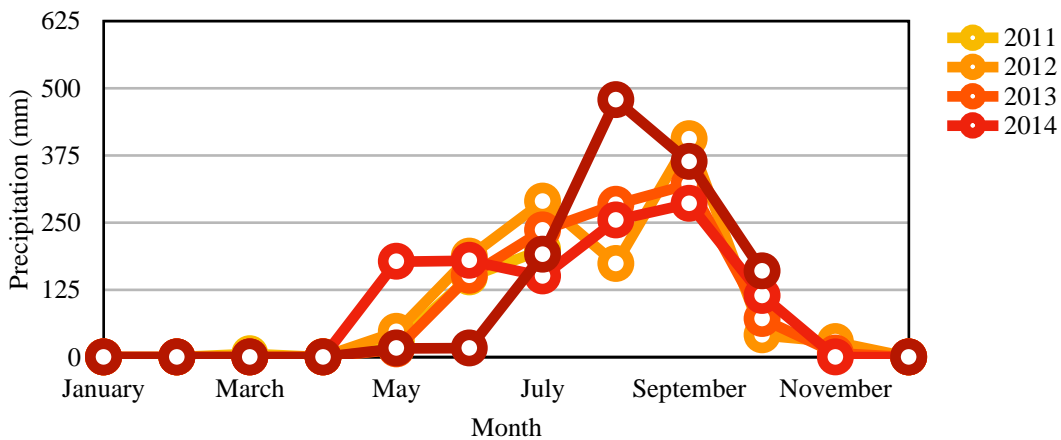


**Figure 11. Mean Precipitation at Fongoli, Senegal (2011-2015)**

86.13) than the test value (t(9)=-2.918, p=0.017).

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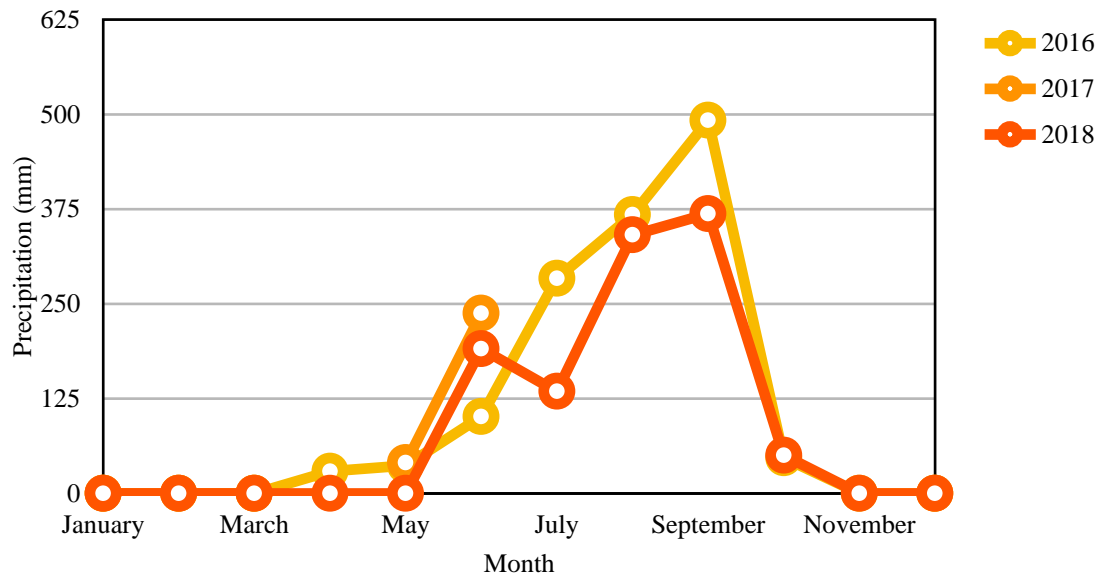
**Figure 12. Mean Precipitation at Fongoli, Senegal (2016-2018)**

## Feeding & Nesting Tree Frequencies

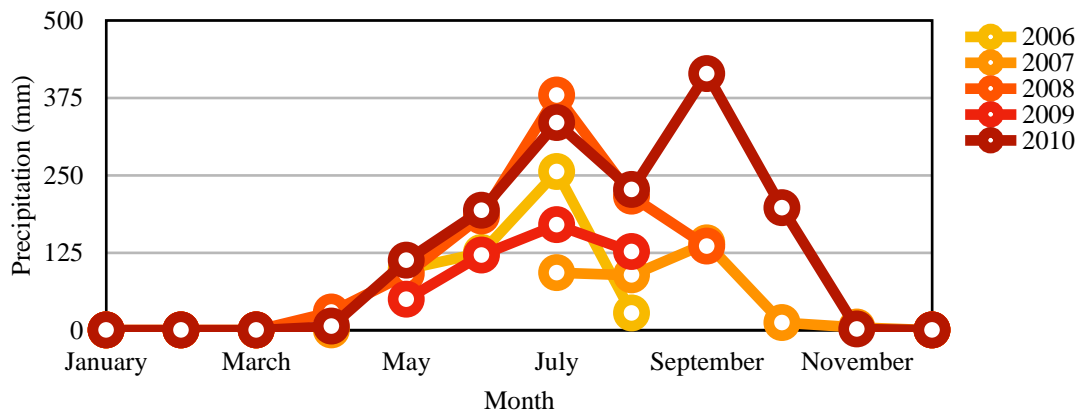Feeding and nesting trees were identified using data from Pruetz (2006), Lind-shield (2014) and unpublished FSCP data on diet to note specific tree genus and species utilized by chimpanzees at Fongoli. Due to Malinke naming traditions, some of the trees on the Fongoli phenology transect were not distinguished by species, notably some *Acacia* (N=4) and certain *Ficus* (N=9) species. In this case, all individual trees of the same Malinke name were considered the same genus and species. A tree was considered 'feeding' if any part of the tree was eaten, regardless of specific part and timing of feeding.

Malinke names and corresponding scientific genus and species were obtained from Micheletti (2018) and unpublished FSCP data. Using phenological transect data from October 2020, the highest percentage of individual trees on the Fongoli tree transect were *Pterocarpus erinaceus* ('Keno') (N=153) at 18.8%. Tree species with the lowest percentage of individual trees was shared by *Zizyphus mauritania* ('Tomborongo'),

25

*Adansonia digitata* ('Sita'), *Landolphia heudelotti* ('Fole'), *Hannoa undalata* ('Keko'), ('Kondonngo'), *Ficus vallis-choudae* ('Sotonunko') and *Ficus umbellata* ('Suro') at 1% of the total transect each. Western chimpanzees frequently use *Pterocarpus erinaceous*, *Anogeissus*, *Khaya*, and *Adansonia* in addition to herbaceous plant species that were not included in the phenological transect data (Badji et al. 2017). Figure 13 contains the frequencies of the 10 tree species along the phenology transect with the highest individual frequency. Table 3 contains all tree frequencies along the phenology transect in addition to 'feeding' and 'nesting' notation.
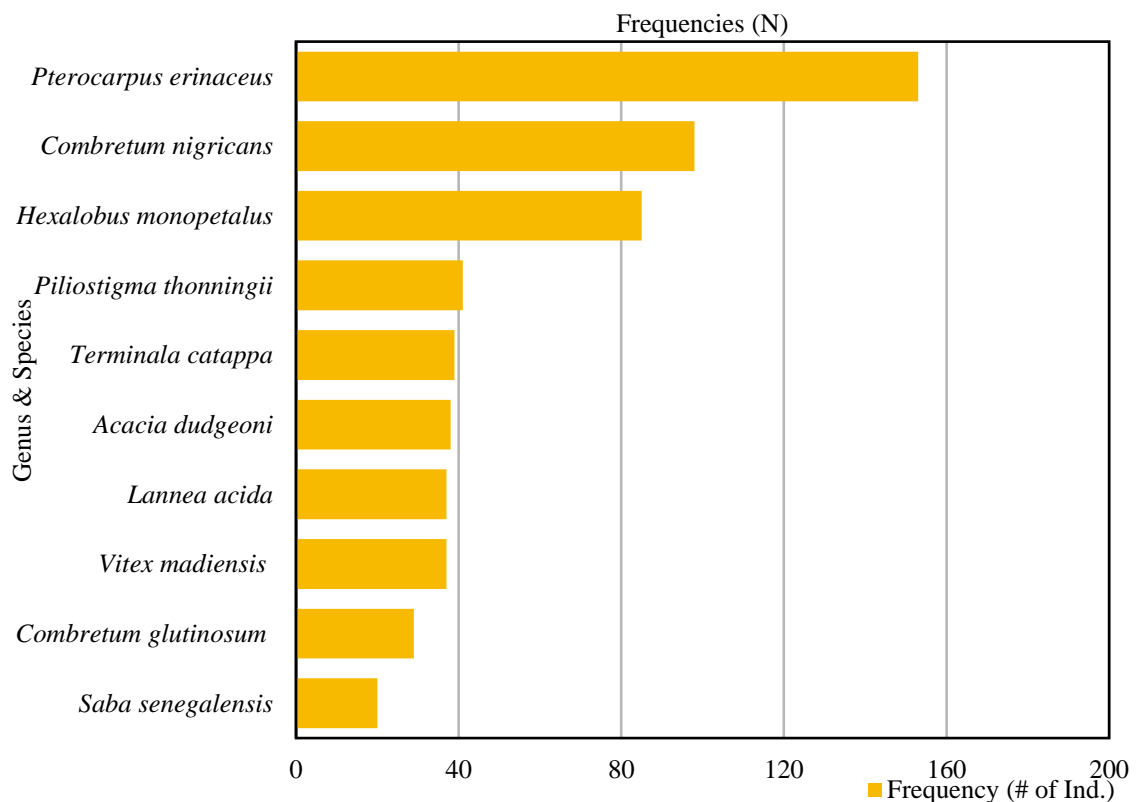


**Figure 13. 10 Highest Tree Frequencies Along Fongoli Phenology Transect**

**Table 3. Tree Frequencies Along Phenology Transect (Fongoli, Senegal)**

| Genus and spe- | Malinke | Frequency | Genus and species | Ma- | Frequency |
|---|---|---:|---|---|---:|
| *Pterocarpus eri-* | Keno | 153 | *Combretum nigricans* | Ku- | 5 |
| *Combretum nigri-* | Diamba | 98 | | Kimbo | 4 |
| *Hexalobus mon-* | Gundje | 85 | *Nauclea latifolia* | Batio | 4 |
| *Piliostigma thon-* | Fara | 41 | | Banidan | 4 |
| *Terminala* | Wolo | 39 | | Wowou | 4 |
| *Acacia dudgeoni* | Tontosaro | 38 | *Khaya senegalensis* | Djalla | 3 |
| *Lannea acida* | Bembo | 37 | *Hannoa undulata* | Kieko | 3 |
| *Vitex madiensis* | Kutufingo | 37 | *Acacia ehrenbergiana* | Ga- | 3 |
| *Combretum gluti-* | Diamba (k) | 29 | *Lannea microcarpa* | Fekho | 3 |
| | Barin | 20 | *Ficus gnaphalocarpa* | Tore | 3 |
| *Saba senegalensis* | Saba | 20 | *Tamarindus indica* | Timbing | 3 |
| *Diospyros* | Kukuo | 15 | *Cassia sieberiana* | Syndjan | 3 |
| *Diospyros* | Kukuo | 15 | *Dischrostachys ci-* | Ku- | 3 |
| *Bombax costatum* | Bunkungo | 14 | *Sterculia setigera* | Kun- | 3 |
| *Cordyla pinnata* | Dougouto | 14 | *Lannea acida* | Bintinkj | 2 |
| *Spondias mombin* | Minkongo | 14 | *Ficus abutilifolia* | Dekhed | 2 |
| *Anogeissus leio-* | Kere | 13 | *Landolphia heudelotti* | Fole | 1 |
| *Cola cordifolia* | Taba | 13 | | | |

**Table 3. Tree Frequencies Along Phenology Transect (Fongoli, Senegal) (cont'd)**

| Frequency (# of Ind.)3 | Frequency (# of Ind.)4 | Frequency (# of Ind.)5 | Frequency (# of Ind.)6 | Frequency (# of Ind.)7 | Frequency (# of Ind.)8 |
|---|---|---|---|---|---|
| *Vitellaria paradoxa* | Se | 11 | | Kato | 1 |
| | Khasara | 10 | *Oncoba spinosa* | Kondongo | 1 |
| *Daniella olivieri* | Santango | 8 | *Combretum sp.* | Konkolinkora | 1 |
| *Hymenocardia acida* | Korokande | 7 | *Lonchocarpus laxiflorus* | Mohoyero | 2 |
| *Hymenocardia acida* | Korokande | 7 | *Ficus ingens* | Sekho | 2 |
| *Combretum michrantum* | Kenkeliba | 6 | *Adansonia digitata* | Sita | 1 |
| *Baissea multiflora* | Banombo | 5 | *Annona senegalensis* | Sounkoungo | 2 |
| | Netto | 5 | *Ficus vallischoudae* | Soutnounko | 1 |
| *Allophylus africanus* | Yirindingo | 2 | *Ficus umbellata* | Suro | 1 |
| | Diouto | 2 | *Gardenia erubescens* | Tankango | 1 |

In regards to feeding, the genera *Adansonia*, *Tamarindus*, *Ficus ingens* and *Ficus umbellata* make up the majority of the metabolic input for chimpanzee daily diets during the dry season (Lindshield 2013).

</span>

## V. DISCUSSION

**NDVI Interpretation and Seasonal Variability**

While NDVI was not empirically calculated for a specific area of the Fongoli
chimpanzee home range, there are visual distinctions between the wet and dry seasons of
both 2016 and 2020 when corrected for atmospheric and surface reflectance. There are
larger areas of denser vegetation in November, 2020 than February of 2020. This could
potentially be due to not all trees having dropped their leaves. Additionally, the overall
habitat from February, 2020 is more homogenous upon viewing. Due to extensive cloud
cover in February, the surface level NDVI visualization appears distorted. Visually, the
blue color is representative of the denser cloud cover, which cannot be corrected for, un-
like lighter cloud cover which can be. However, the NDVI scientific outputs between
February and November are not drastically different from each other. GIS NDVI maps
are included in Appendix 1.

**Phenological Trends & Fluctuations**

As noted by Elzinga and colleagues (2007) a certain degree of phenological vari-
ation is necessary to facilitate robust genetic populations in plants. If all individuals of a
plant population flower or fruit synchronously, there will be proportionally less variation
than if there is staggered phenological stages. This staggered development across a popu-
lation is also mutually beneficial for foraging animals: if all plants fruit/flower synchro-
nously, the window of optimal foraging time will be small.

The significant association of ripe fruit presence and new leaf availability be-
tween Phase 1 (2006) and Phase 2 (2020) during the 'Wet' series is potentially due to
corresponding climatic conditions that were present in both of the phases. Both phases

experienced similar mean temperatures, with no dramatic fluctuations in precipitation. Significant association between new leaves of Phase One (2006) and Phase Two (2020), additionally, could be due to corresponding temperature and precipitation trends occurring within the parameters of the two phases.

As stated by Chapman et al (2005), phenological data itself does not specify the intensity of fruiting events or the amount of fruit produced during a specific fruiting season (Chapman et al. 2005). As such, the phenological data collected is not the only data assessed through statistical analysis or the most important data assessed; rather, the phenological data provides an environmental data aspect to assess how the trees on the phenological transect react to potential climatic change.

**Temperature & Precipitation Fluctuations**

Previous research has indicated that precipitation and temperature fluctuations for mean climate in Senegal between 1971 to 1998 were not significant (Fall, Niyogi, & Semazzi 2005). The fluctuations during this period are overall not statistically significant, even with previous droughts occurring between 1911-1913, 1940-1943 and 1968 to more recently (Bodian et al. 2020). Reflecting this microclimatic pattern, the precipitation data obtained from Fongoli and NOAA land station weather databases does not show overarching deviation from the mean precipitation value of 82.4mm for the study period.

Temperature data did not show any significant differences from the mean temperature value of 29.6°C. This could be due to the small timeframe from which data was obtained but also due to the overall lack of temperature fluctuation between historical droughts documented in Senegal. Additionally, the use of mean temperature taken from

the collected data is subject to introduce error, as 29.6°C is an average of the mean temperature from 2006 to 2018. This same introduction of error applies to the use of both maximum and minimum temperature test values as well.

For maximum temperature, the only statistically significant year deviating from the maximum test value of 32.27°C was 2016. While there were no noted temperature shifts for this region during 2016, it could be that a smaller temperature shift occurred that was not reflected across the Senegalese region as a whole. As temperature from National Oceanic and Atmospheric Administration (NOAA) land stations are area specific, there could be temperature changes that occurred specifically in the areas of Kedougou and Tambacounda that are not reflected across a broader area.

**Legacy Effects**

Due to the importance of temperature as previously stated by Chapman and colleagues (2005), temperature should be assessed critically as a driving component when assessing the importance of phenological shifts. As temperature fluctuates relatively little, the likelihood that phenological shifting is dependent on average temperature alone is fairly low, specifically in arid environments. Modeling of phenological shifts traditionally have relied on a small percentage of the overall biome, often taken from land sourced sites (Peñuelas et al, 2021). As such, these previous models are only a snapshot of the larger ecosystem and subject to increased temporal inconsistencies.

**Climate Change on Chimpanzees**

While the effects of climate change are expected, and have already in certain areas been shown, to affect plants, climate change also affects the chimpanzee individuals themselves. The current and predicted climatic trends found at Fongoli are expected to

produce an environment within approximately 80 years that will be stressful for the chimpanzees in regards to thermoregulation (Miller, 2020). As chimpanzees operate on a threshold similar to plants, the increasingly erratic climate changes found in the Sahel region pose threats to the chimpanzees when discussing thermoregulatory success. Additionally, as water is a limiting resource at Fongoli when looking at chimpanzee ranging distance, increasingly erratic precipitation will further stress the ability of the Fongoli chimpanzees to utilize their environment.

## VI. CONCLUSION

As noted by Hatfield and Prueger (2015), the impacts of climate change are largely dependent on the individual plant species. With expected air temperatures possibly rising to above the optimal range of pollen production many pollen producing species, or species which use wind to transport pollen, may see a decrease in fruit production (Beggs, 2004). Additionally, the rising air temperatures may shorten growing seasons for plants that depend on cooler temperatures to germinate and grow. In addition to temperature shifts precipitation irregularities in Senegal, as noted by Pruetz and Herzog (2017), impact optimal growth patterns for plants. A consistent amount of precipitation is optimal for plant use, rather than irregular precipitation at high volumes.

In addition to the responses of individual species to climate change, the collective knowledge about how abiotic, extant species will respond to impending climate change is still ongoing (Bellard et al, 2012). While we can use extinct fossil species as proxies, there are limitations to what scientists can gain in regard to applied understandings.

### Impact on Chimpanzee Behavior & Habitat Use

Based on the phenological shifts in this study, the habitat quality at Fongoli is expected to remain consistent in the near future. This statement bares the impact of anthropogenic influence as well as rising global temperatures in the future (Graham et al, 2016). This estimation of chimpanzee habitat use also relies on the assumption that chimpanzees will use their environment optimally and rely on behavioral flexibility to utilize resources (Karline, 2016). Previous research indicates that chimpanzees behaviorally respond to seasonal and unpredictable environmental events, resulting in a diversified behavioral repertoire  (Kalan et al, 2020). This behavioral flexibility takes into account both short-

term and long-term environmental flexibility. The resiliency of Western chimpanzees at Fongoli also relies on the longevity of shared fruit resources including *Saba senegalensis*, which is anticipated to shift dispersal pattens due to human consumption (Waller & Pruetz 2016).

**Anthropogenic Modification of the Environment**

As previously stated, anthropogenic disturbance is a leading contributor to both climate change and the rapid decline in non-human primate populations (Zhao et al, 2019). By better understanding the phenological trends of trees utilized by Western chimpanzees, primatologists can better inform local peoples on issues of selective harvesting, agriculture, and prescribed burning (Pruetz & Herzog, 2017). Primatologists can also utilize phenological data to understand seasonal ranging patterns of specific primate communities and how to incorporate this information into conservation plans. By understanding climatic data including precipitation and temperature fluctuations, scientists can better gauge potential future reactions to drastic climatic events. Additionally, scientists can assess past events to understand if present climatic shifts are a significant deviation from previous weather cycles.

**Estimating Phenological Trends**

Due to the nature of the relationship between temperature, precipitation and phenology, the estimation of future phenological events is difficult in the Sahel region. With historical drought events occurring, Senegal has the potential to experience another drought event in the near future (Tall et al 2017). However, as phenology is dependent on a myriad of factors, phenological response to precipitation changes alone is difficult to

assess. While the data collected at Fongoli is longitudinal, the need for additional pheno-

logical ground data throughout other areas of Senegal is necessary to form a more com-

prehensive view. Additionally, it is important to find viable methodologies when measur-

ing phenology; as many tree species can take generations to bear fruit, methods of pheno-

logical recording must take into account decades worth of potential climatic input. As

phenology operates through windows of optimality, the understanding of how optimality

windows shift is important to phenology shifts (Visser & Both 2005).

**Future Directions**

The need to understand the long-term effects of climate change on the impacts of

phenology is increasingly more important. While the results of this specific study do not

suggest phenological shifts are occurring under the current conditions of previously re-

search climate change, it is important to note that the life histories of woody plant species

are prolonged when compared to herbaceous plant species. While the findings do suggest

that phenological differences between research phases have occurred, an important ques-

tion to pose is: at what threshold do differing biomass outputs relate to climate change?

Therefore, the current amount of data, which is less than the length of one chimpanzee

generation, may not be enough to assess long-term phenological trends in relation to cli-

matic shifts and life histories. In addition, the use of varying phenology assessment meth-

ods may not be valid in order to understand longitudinal phenological changes or the phe-

nology scoring methods used are not precise enough to address gradual change across

multiple growing seasons.

Future research should incorporate other abiotic factors affecting phenology aside from precipitation and temperature. As previously stated, the rainy season has in more recent years become erratic in terms of onset time (Pruetz & Herzog, 2017); understanding the onset time in addition to duration of the rainy season once onset has begun, can inform about plant drought resilience.

**Figure 14. GIS NDVI Map of Fongoli Chimpanzee Home Range and Associated Geographic Landmarks for February 2016.**
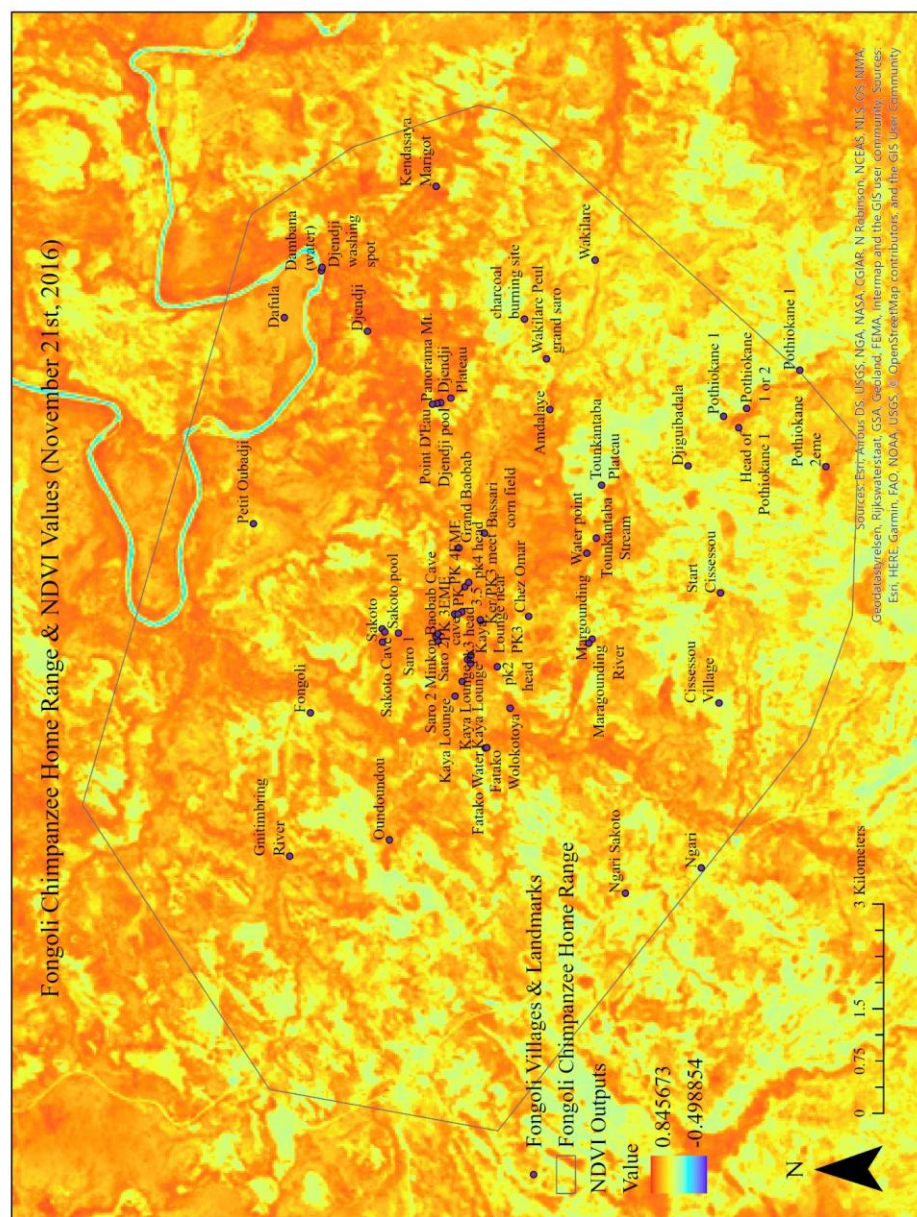
**Figure 15. GIS NDVI Map of Fongoli Chimpanzee Home Range and Associated Geographic Landmarks for November 2016.**
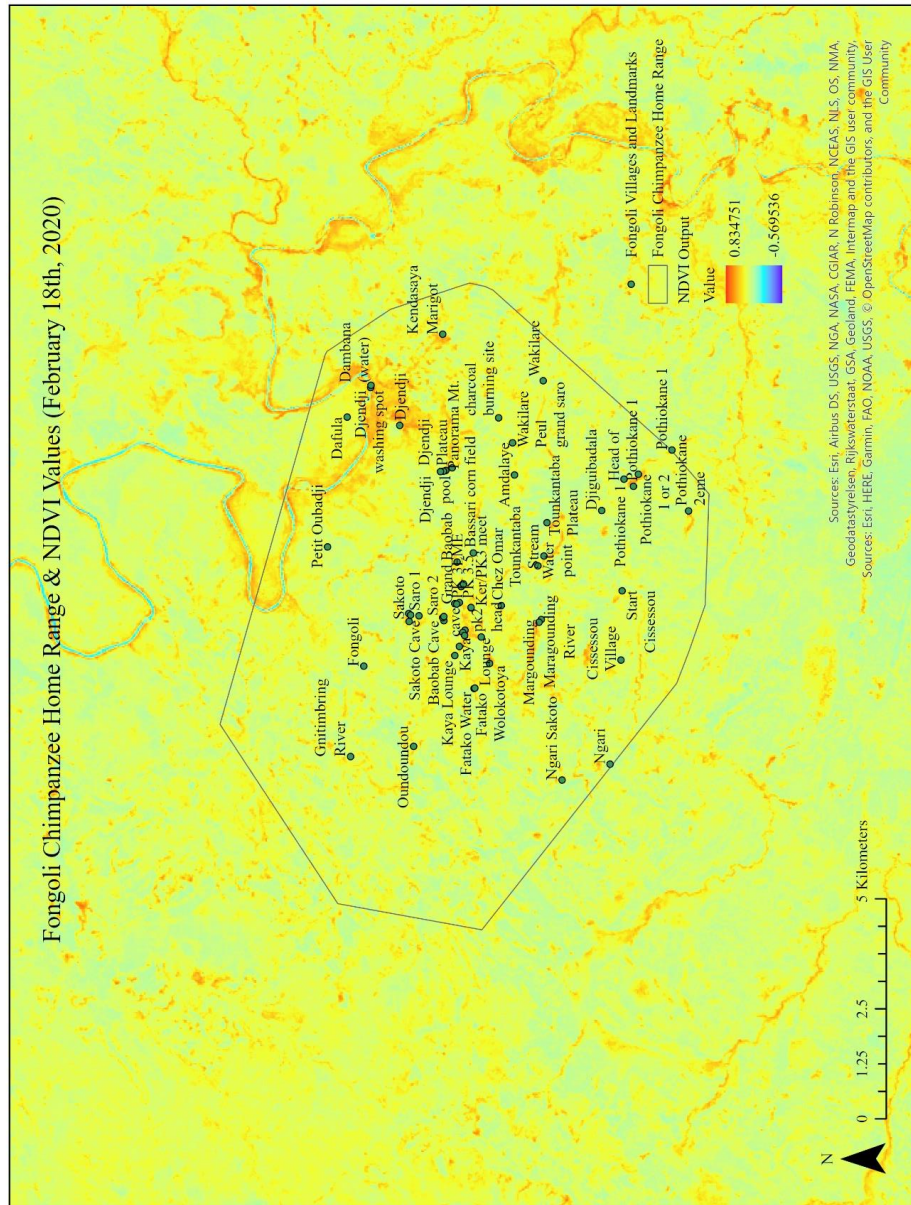
**Figure 16. GIS NDVI Map of Fongoli Chimpanzee Home Range and Associated Geographic Landmarks for February 2020.**
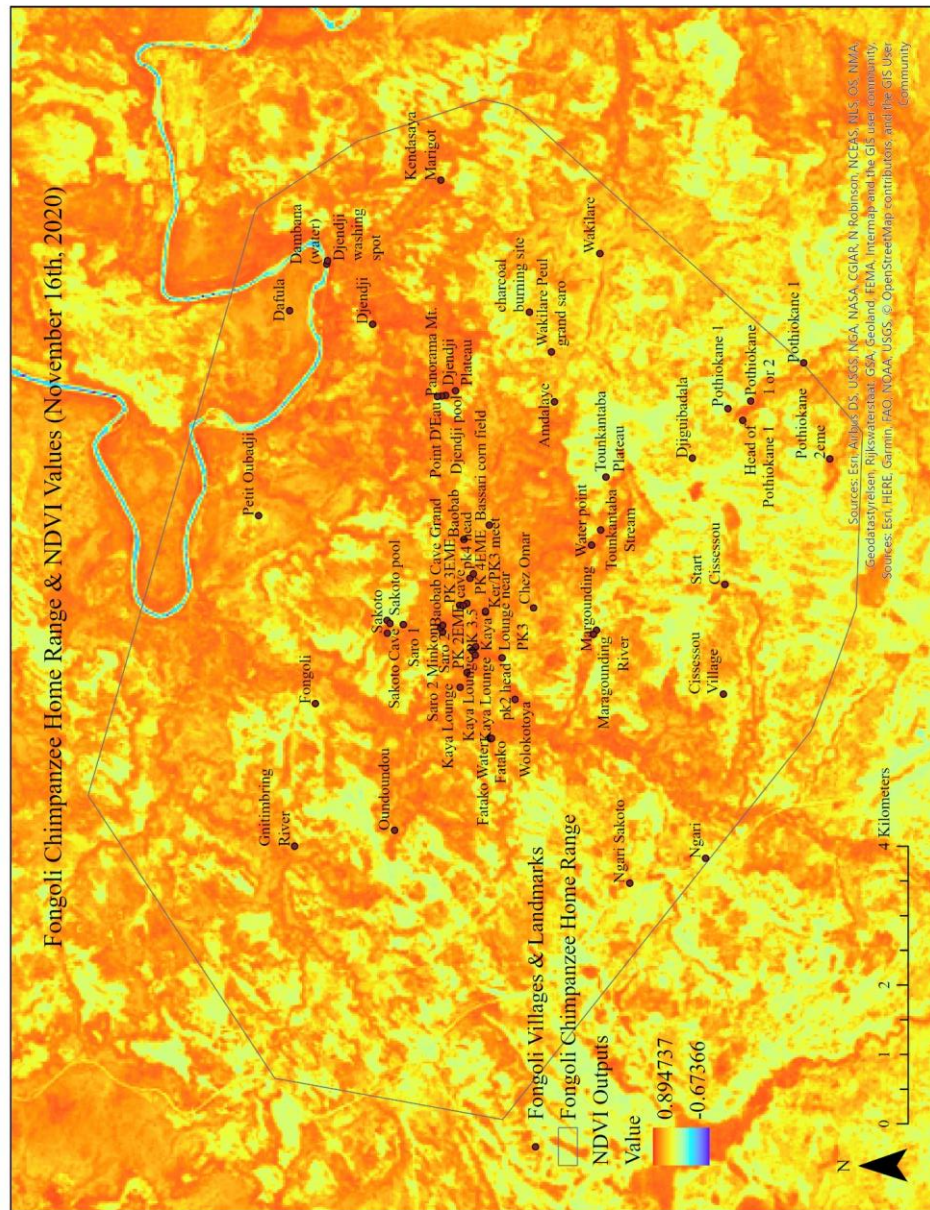
**Figure 17. GIS NDVI Map of Fongoli Chimpanzee Home Range and Associated Geographic Landmarks for November, 2020.**

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