Research Proposal: Addressing the connectivity of *Raphia taedigera* palm swamps in Central America

Gabriel Muñoz

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Contents

Universiteit van Amsterdam: MSc. Biological Sciences, track: Ecology and Evolution

Student: Gabriel Muñoz

Supervisor: Harry Seijsmonsbergen

Co-supervisor: Renske Onstein

Examiner: Emiel van Loon

1 Introduction

Flodded ecoystems are one of the most conspicous, yet endangered, landscapes for the most part of lowlands in tropical regions (Myers 2013, Junk et al. 2013). It is known that not all plant species have the capacity of adaptation needed to survive in annegated environments or support the direct effect of water. In general terms, such ecosystems tend to be dominated by monocotyledons species, principally herbaceous and palm species (Myers 2003). In coastal regions of Central America, especially in the Carribean region, palm species from the genus *Raphia*, *Manicaria* and *Attalea* dominate large land extensions for which soils have low drainage and high saturation of water (Myers 2013). This wetlands resemble those of *Mauritia flexuosa* in the Amazon and *Metroxilon sp.* in Southeast Asia (Henderson et al. 1995; Myers 1990).

Raphia taedigera is a palm species from the Lepidocarioides group and is the only representative of the genus *Raphia*, which is an African clade, for the Americas (Uhl and Dransfield 1987; Carney and Hiroaka 1997). It is distributed in Central America, along the Carribbean lowlands from Nicaragua to Panama and the south Pacific coast of Costa Rica (Sandi et al. 2013) forming sometimes monotypic extensions called **Yolillales** (Figure 1). In South America it is found in Colombia in coastal areas along the gulf of Urabá and Atrato (Espinal and Montenegro 1963) and in Brazil in the islands of the Amazon delta (Kanh and Moussa 1994). In Africa, this palm species is found in coastal periodically flodded swamps in Gabon, Camerún and Nigeria. *Raphia taedigera* is characterized by its long pinnate leaves which can reach up to 25 meters long and 3 meters wide. *Raphia taedigera* has an aseasonal phenology and its reproduction goes troughout the year. The fruits of *Raphia taedigera* are oblong and contain each a single seed. The fruits do not float and are covered by imbricated, golden to brown scales resembling a closed pine cone (Myers 2003; Myers 1984) (Figure 2. A

Figure 1: Raphia taedigera palm swamps. Note the monotypic growth form in flat areas next to slopes and rivers in coastal regions of Central America

single plant of *Raphia taedigera* may produce several infloresences over its life and dying shortafter (Wake et al. 2006).

At first, because of the presence of *Raphia taedigera* in Africa and their non-continous distribution along the coastlines of America, it was suggested that this species was introduced to the Americas with slave ships from Africa (Otedoh's 1977). However, this hypothesis has not been supported by pallinological data which found the presence of communities of *Raphia taedigera* for at least 2800 +- 90 years (Urquhart 1997; Carney and Hiroaka 1997). Moreover, there is evidence of pre-columbian use of *Raphia taedigera* in Bocas del Toro, Panama (Wake et al. 2006) suggesting that the arrival of this species to the Americas pre-dates the arrival of Europeans. The current patchy distribution of populations of *Raphia taedigera* along the Americas could be product of independant arrivals from Africa in floating vegetation racks since the Cretaceous or remnants from a past continous distribution influenced by Pleistocene sea level rises (Fairbanks 1989; Urquhart 1997).

Palm swamps provide important ecosystem services for the tropics. Despite their small relative coverage, they are key to regulate carbon fluxes. Palm swamps are net carbon sink. Swamps releases important quantities of methane (CH4), a house-warming gas, to the environment (Zuffada et al. 2016). However, most of the carbon is recuperated by the organic material in the palms. When those landscapes are transformed into grasslands flooded swamp areas are transformed into net sources of carbon to the atmosphere. Despite of showing a lowest alpha diversity compared to sourrounding primary humid evergreen forests, palm swamps serves as important refugia to several endangered species such as: Tapirs (*Tapirus bairdii*), Pecaries (*Pecari tajacu*, *Tayassu pecari*), jaguars (*Panthera onca*), puma (*Puma concolor*), ocelot (*Leopardus pardalis*,*Leopardus wiedii*) (Yaap et al. 2015). These species tend to be observed more frequently inside palm swamps. Yolillales are also importants for endangered bird species such as the sunbird *Eurypiga helias* or the Harpy Eagle *Harpia harpyja* (Beneyto 2013; Calvo-Gutierrez 2013).

Table 1: Animal use of *Raphia taedigera* patches (Yolillales), from Yaap et al. 2015. (* = unfrequent)

Species	Use
Nasua narica	Habitat
Procyon sp.	Habitat
Pecari tajacu	Food source
Cebus capucinus	Food source
Leopardus pardalis	Habitat
Tamandua mexicana	Habitat
Dasyprocta punctata	Habitat
Cuniculus paca	Habitat*
Puma yagoaroundi	Habitat
Conepatus semistriatus	Habitat
Dasypus novemcinctus	Habitat*
Odocoileus virginianus	Habitat*
Philander opossum	Habitat
Muridae	Habitat
Sciuridae	Habitat
Aramides cajaneus	Habitat
Columbidae	Habitat
Eudocimus albus	Habitat
Ardea alba	Habitat
Egreta thula	Habitat
Egretta caerulea	Habitat
Tigrisoma mexicanum	Habitat
Agamia agami	Habitat
Butorides virescens	Habitat
Mycteria americana	Habitat
Tayassu pecari	Food source
Tapirus bairdii	Food source
Panthera onca	Habitat

Because *Raphia taedigera* fruits do not float (Myers 2013), genetic exchange between populations of *Raphia taedigera* in Central America should rely on animal mediated long distance distance dispersal events (Zona and Henderson 1989). Measuring 5-7cm large and 3-4cm wide (Figure 2), few animals consume the fruits of *Raphia taedigera*. Inmature seeds are consumed by capuchin (*Cebus capucinus*) and spider (*Ateles geoffroyi*) monkeys. However, their way to consume the fruit makes them more seed predators rather than suitable seed dispersers agents (Myers 2013). Pecaries find the seed to hard to eat or they consume the fruit with mastication, effectivelly destroying the seed (Myers 2013). Tapirs (*Tapirus bairdii*) are considered the only viable animal seed disperser agent for *Raphia taedigera*, tapirs are the only animals able to consume the fruit entirely and disperse their seeds away from the mother plant (Chasot et al. 2006; Myers 2013). Central american tapirs have been documented to use more intensively lowland secondary forests and *Raphia taedigera* palm swamps (Yolillales) rather than lowland primary forests or pre-montane forests (Naranjo 1995; Naranjo 2009), moving by regions with easy slopes (Tobler 2002). Fragoso (1991) suggested that tapirs prefer foraging in flooded flat areas. Despite of fruits of *Raphia taedigera* are available all year round, tapirs they tend to have a preference to forage in yolillales in the dry season (Yaap et al. 2015). In addition, tapirs also have a preference to defecate near water (Naranjo 1997). In South America, tapirs acts as efficient dispersers of large seeded palm species such as *Mauritia flexuosa* or *Maximiliana maripa*, species which also grow in monospecific patches in the amazonian forests (Fragoso et al. 1991).

To support large scale conservation objectives, transfronterize conservation laws should be applied similar to the Mesoamerican biological corridor between Nicaragua and Costa Rica established in 1997 (Chassot et

Figure 2: Fruit of Raphia taedigera

al. 2005). Such initiatives require detailed information on species distribution an population connectivity at larger spatial scales. Remote sensing technology allows the development of adequate frameworks and baselines to monitor biodiversity from space and throughout time (e.g. Forest Watch) (Hansen et al. 2013; Agresta et al. 2015). Functional connectivity, (i.e. The ease of movement among points or resource patches) (Belisle et al. 2005) is highly determined by the physical geography of the landscape (Correa et al. 2016). Knowledge on the spatial connectivity of populations is fundamental to apply adequate onservation measures. Mantaining the connectivity of populations ensures the proper function of ecological processes such as gene flow, migration, re-colonization and climate change adaptation (Correa et al. 2016; Rudnick et al. 2012).

In this context, population patches of *Raphia taedigera* in Central America are hypothesized to acts as hubs in a flowing seed dispersal network which is mediated by the movements of Central American tapir (*Tapirus bairdii*) populations. Thus, the degree of functional spatial connectivity between *Raphia taedigera* patches can be measured with concepts from Circuit Theory (McRae 2006; McRae et al. 2008). Connectivity is represented as a current flow (i.e. "The spatial distribution of dispersal probability of random walker (per cell) through all habitat patches" (McRae and Beier 2008; Spear et al. 2010; Zeller et al. 2012; Correa et al. 2016) relative to a resistance surface (i.e. The degree of difficulty (cost) of an organism to move through the landscape) (Singleton et al. 2002; Spear et al. 2010; Correa et al. 2016). To measure the functional connectivity between *Raphia taedigera* patches, the following research questions are proposed:

1: How does the functional connectivity between *Raphia taedigera* patches varies spatially?

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H1: Patches of Raphia taedigera form four clusters of connected patches: 1=North CostaRica and South
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2: How does the functional connectivity between *Raphia taedigera* patches varies temporally?

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H2.1: Connectivity between patches varies temporally in relation with the dry - wet season and flooding
H2.2: Connectivity between patches varies temporally in relation with human density. Patches will become
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3: Are there any bottlenecks in the spatial connectivity of patches of *Raphia taedigera*?

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H3: Connectivity bottlenecks are formed near Puerto Limon in Costa Rica, near the Nicaragua Lake and
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2 Methodology

The geographic distribution of Yolillales have been evaluated for Central America in Nicaragua, Costa Rica and Panamá (Agresta et al. 2015 [Costa Rica]; Sandi et al. 2013 [Costa Rica - Nicaragua]; Vreugdenhil et al. 2002 [Central America]). Yolillales have been mapped using orthophotos (Sandi et al. 2013); with remote sensing using LANDSAT series data (Agresta et al. 2015) and with a mixture of expert knowledge, remote sensing and orthopothos (Vreugdenhil et al. 2002) (Figure 3). The homogeneous characteristic of the

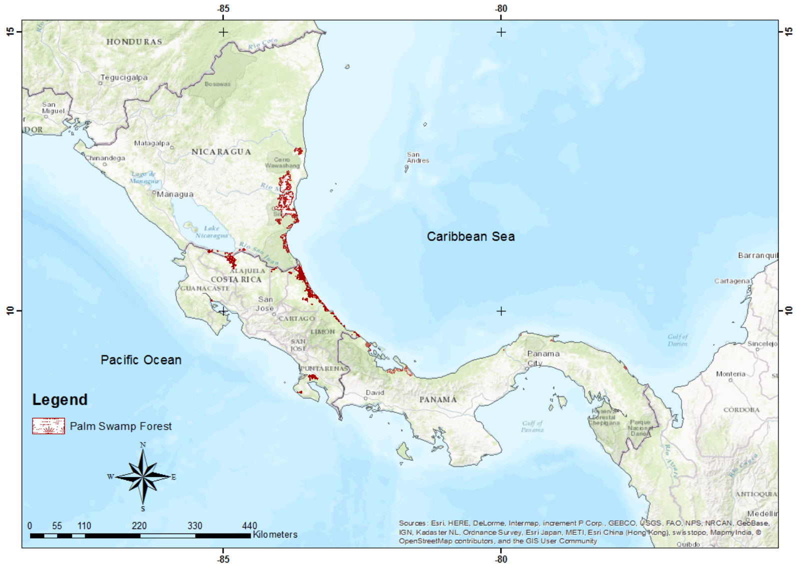

Figure 3: Map of the study area. Palm swamp forest distribution is highligted in red, data come from an aggregation of sources (Vreugdenhil et al. 2002, Agresta et al. 2015)

canopy facilitates the observation of Yolillales using spaceborne imagery. Synthetic Aperture Radar (SAR) sensors, as they can observe through clouds, are particulary suited for biodiversity monitoring efforts in the tropics, where cloud-cover often pose a problem for optical based sensors such as LANDSAT (Agresta et al. 2015; Simard et al. 2002). There is a need to develop methods to quickly quantify spatial extent and indundation state of wetlands (Podest 2011). SAR data has already been used to map coastal tropical regions succesfully in Gabon (Simard 2002); Costa Rica (Verhoeye and De Wulf 1999) and Borneo (Englhar et al. 2011). Additionally, SAR has been used to map *Mauritia flexuosa* swamps in the amazon floodplains of Perú (Podest et al. 2011).

To answer the proposed questions, I will follow the proposed workflow as described in (Figure 4). From a detailed literature review (Haddaway et al. 2016) including grey literature, data on *Raphia taedigera* records and distribution will be recorded to identify the spatial geographical location of *Raphia taedigera* patches in Central America. The literature review additionally will be focused to retrieve natural history characteristics for the central american Tapir (*Tapirus bairdii*), such observations (e.g. Tapirs avoid at least 290m around human populated areas) will be used together with additional remote sensing data (e.g. Digital Elevation Models (DEM's) and Forest Coverage) to generate spatial variables relative to the tapir seed dispersal characteristics. Those variables together with a tapir species distribution model (SDM) and Sentinel 1 SAR derived information about water reflection and environment humidity (Twele et al. 2016), will be standarized and aggregated to generate the resistance layer (Correa et al. 2016). Landscape connectivity connectivity scenarios (e.g. Webs of minimum cost corridors (McRae and Sha 2011; Beier et al. 2011)) based on current flow theory analyses (Example: (Figure 5) will be applied to answer the research questions proposed.

Data from Sentinel 1 will be obtained from open sources. Data for SENTINEL 1 can be found in the European Space Agency (ESA) data hub (https://cophub.copernicus.eu/) and processed L1 data is available in Earth Engine Datasets. Tapir occurrences will be retrieved from the literature review and GBIF. A species distribution model, with information on habitat suitability will be constructed with MAXENT and BIOCLIM variables. Topography data will be derived from the the 30m resolution Shuttle Radar Topography Mission (SRTM) data. Population density data come from the WorldPop Dataset and Forest Coverage from the Global Forest Watch Dataset. Sentinel 1, SRTM, WorldPop and Forest Watch datasets are openly available from the Google Earth Engine API. In addition to already incorporate open-source datasets, Google Earth Engine allows for cloud based computing, important for large scale analysis.

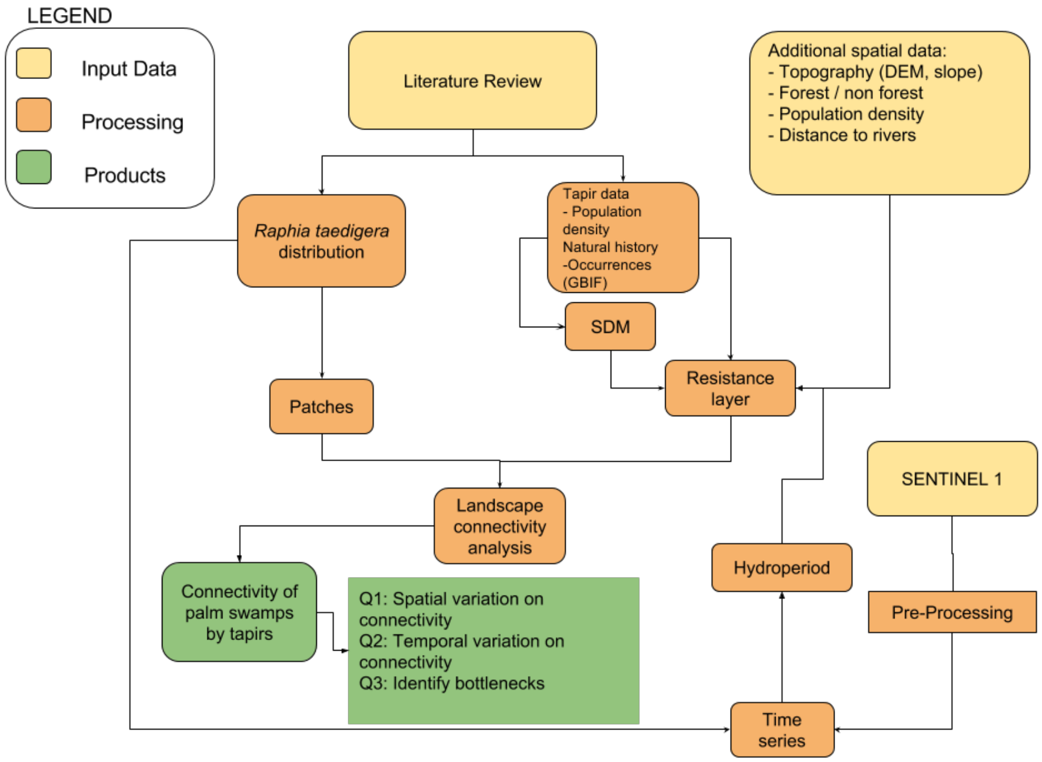

Figure 4: Proposed workflow

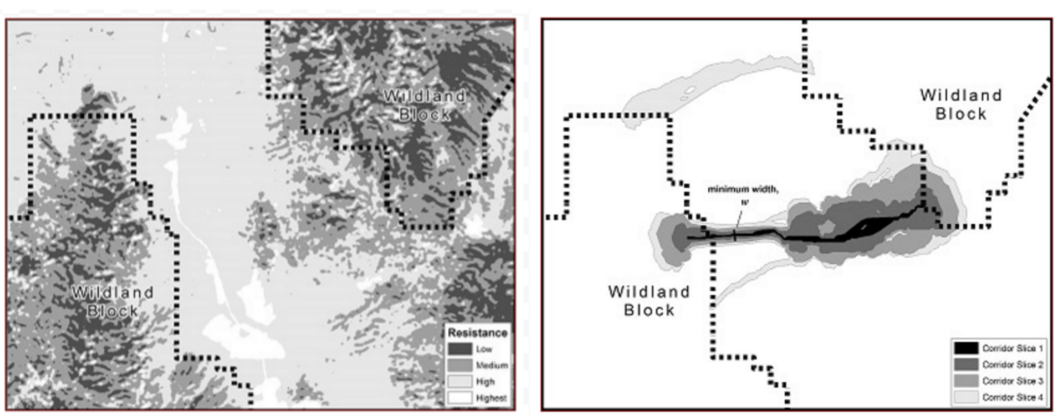

Figure 5: Examples of corridor outputs using current flows

3 Timeline

Activity / Date	Feb	Mar	Apr	May	Jun	July	Ago
Proposal	x	x					
Data retrieval	x	x					
Processing		x	x				
Analysis			x	x	x	x	
Writing report				x	x	x	x
Final presentation							x

4 Techniques and software (which techniques will be used, which new techniques are learned by the student):

- Detailed literature review for species records and natural history documentation
- ArcGIS
- Landscape connectivity analysis (Software: CONEFOR / CIRCUITSCAPE / Linkage mapper) [new]
- Google Earth Engine [new]
- R

5 Literature of interest

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