Effect of shade on *Antigonon leptopus* (Corallita) growth and germination rate

An experimental research conducted in Saba (Dutch Caribbean) as a potential control method for Corallita

View from Saba. Autor's own source, 2018

Name: Judit Planas i Puig

Student number: 5936691

Student mail: j.planasipuig@students.uu.nl

Master programme: Sustainable Development

Track: Environmental Change and Ecosystems

Thesis credits: 30ETC

Supervisor: Prof. dr. Max Rietkerk

Second supervisor: Jetske Vaas

August 2018

ABSTRACT

Non-native species can cause loss of biological diversity and threaten society's well-being when they become invasive. One of the most problematic invasive species currently affecting the Dutch Caribbean islands is a plant called Corallita (*Antigonon leptopus*). This non-native species, originally from Mexico, was introduced to the Caribbean islands at the beginning of the twentieth century as an ornamental plant. But the plant quickly expanded beyond its area of introduction and, once established, it is difficult to eliminate due to the production of tuberous roots that can propagate vegetatively.

The Caribbean islands are of great importance to the world's biodiversity. In the Nature Policy plan for the Caribbean Netherlands invasive species, such as Corallita, are recognized as one of the biggest threats to this delicate biodiversity, thus, their management is of critical importance.

There is an insufficient amount of background literature about control methods and management of Corallita. Therefore, further research into control, ecology, plant phenology and factors regarding growth are needed in order to find an effective solution. One of the factors that there is still no knowledge about is the effect of shade on Corallita. It has long been known that light is the most important factor influencing plant growth, morphology, flowering time and plant productivity among others. Hence, it is necessary to comprehensively understand changes that occur when switching between shade and sun exposure in this invasive species.

For this purpose, several field experiments were conducted in the island of Saba, one of the Dutch Caribbean islands affected by the presence of this plant, to evaluate the responses of Corallita's growth and germination under different treatments of light availability. Corallita seeds and seedlings were exposed to 4 shading treatments (noncovered, partial shade, heavy shade and total covered) during approximately one month to quantify morphological parameters, such as plant height and weight, leaf number and area as well as seed survivorship rate. Nevertheless, results showed no significant differences between groups, suggesting that shade does not play a substantial role in the growth and germination of Corallita.

Additionally, since most of the land in Saba is privately owned, it is as well important to get an insight of what the landowners are willing to do to get rid of the plant. Thus, semi-structured interviews, together with a focus group meeting, were performed aiming to identify which control method is more appropriate for landowners, in terms of their resources and necessities. The results showed that the economic factor is the most suppressing when controlling Corallita and that a manual method is currently seen as the most appropriate for them.

Key words: *Antigonon leptopus*; Corallita; Germination; Growth; Light intensity; Shading

TABLE OF CONTENTS

1. INTRODUCTION

Biological invasions cause ecological and economic impacts across the globe (Vilà et al., 2011). Non-native species can cause loss of biological diversity (for example genetic and ecosystem diversity) and threaten the well-being of humans when they become invasive (Schlaepfer, 2011). There are several examples of literature about the impacts of biological invasions in different ecosystems; various invasive plants are known to decrease local plant species diversity (Vilà et al., 2006; Gaertner et al., 2009; Hejda et al., 2009; Powell et al., 2011), increase ecosystem productivity and modify the rate of nutrient cycling (Liao et al., 2008; Ehrenfeld, 2010), and hence, they can impact upon ecosystem services and human welfare (Pejchar & Mooney, 2009). In addition, the Millennium Ecosystem Assessment (2005) recognized biological invasions as one of the five main causes of biodiversity loss.

Impacts of invasive species are sometimes rapid and dramatic, especially when they result in the transformation of ecosystems. Examples include invasive grasses that radically change fire regimes or invasive insects that transform ecosystem functioning by altering carbon, nutrient and hydrologic cycles (Pyšek & Richardson, 2010). Non-native predators and herbivores can cause extinctions of native species, particularly on islands and in freshwater ecosystems (Pyšek & Richardson, 2010; Wilcove et al., 1998). Negative effects on biodiversity are generally the main concern associated with biological invasions, but invasions also have serious implications for human well-being. Most humans rely on alien species for the majority of their food requirements and other basic necessities (Pyšek & Richardson, 2010).

Apart from their threat to biodiversity and ecosystem services, invasive species have a significant socio-economic impact. By damaging commercial crops, reducing yields for agriculture, forestry or fisheries, causing land degradation and interfering with industrial activities, non-native species are responsible for annual economic losses on the order of billions of U.S. dollars per year, according to Pimentel et al. (2001). Invasive species, therefore, contribute to social and economic instability, placing restrictions on sustainable development, economic growth, poverty mitigation and food security (Millennium Ecosystem Assessment, 2005). Concretely, it is estimated that the 79 most harmful invasive species had caused damage of $97 billion in the USA since 1906. Annual losses to pests were estimated at US$ 6.24 billion in Australia, US$ 42.60 billion in Brazil, US$ 78.50 billion in the USA and so on. Worldwide, the costs of damage caused by invasive species have been calculated at US$ 1.4 trillion per year, in other words, close to 5% of global GDP (Pimentel et al., 2001).

As a result, governmental agencies and non-governmental organizations are frequently mandated or have chosen to prevent the introduction of non-native species and minimize their negative effects (Millennium Ecosystem Assessment, 2005; Schlaepfer, 2011).

On the other hand, in some cases, non-native species can also provide benefits. For example, numerous species have been repeatedly and deliberately introduced outside their native range for agricultural, ornamental and recreational purposes (Ewel et al., 1999). As a result, non-native species are integrated into the culture and economies of most countries. There have also been numerous recent examples of non-native species contributing to the achievement of conservation objectives (Schlaepfer, 2011).

However, one of the main drivers of biological invasions are humans. As Hulme (2009) states, humans have transported and imported plant and animal species for a long time. Human activities have also greatly increased the rates of immigration by deliberately or accidentally transporting and introducing large numbers of species to areas beyond normal biogeographic barriers to their spread, where they may establish viable populations (Bellard et al., 2016). Concretely, a widely held defining moment in biological invasions dates as far back as 1500 AD, a period associated with the end of the Middle Ages, the European rediscovery of the Americas, global exploration, the birth of colonialism and the start of radical changes in patterns of human demography, agriculture, trade and industry. However, in recent decades, the world has entered a new phase in terms of magnitude and diversity of biological invasions, the era of globalization (Hulme, 2009). Globalization of trade and industry has resulted in an increased mobility of people and belongings and the associated transport of plants, animals and microorganisms (Pyšek & Richardson, 2010).

Nevertheless, it is important to mention that the problem of biological invasions will be exacerbated in the future by climate change (Pyšek & Richardson, 2010). As Hellmann and colleagues (2008) stated, climate change is projected to significantly alter biodiversity, causing changes in phenology, genetic composition, species ranges and affecting species interactions and ecosystem processes. Invasive species will also respond to climate change and their responses will have, once again, ecological and economic implications. Climate change will also challenge the definition of invasive species as some taxa, which were previously invasive, may diminish in impact and other, previously non-invasive, may become invasive; and many native species will shift their geographic distributions, moving into areas where they were previously absent. These are all reasons to prudently postulate what is meant by an invasive species and other concepts related to biological invasions (Hellmann et al., 2008).

In the past 20 years, an exponential growth in research on biological invasions has been observed, but there is still a lack of consensus in relation to the terminology and model frameworks used by ecologist for the invasion processes (Blackburn et al., 2011). This results in an unclear range of concepts and definitions surrounding this topic. As Colautti & MacIsaac (2004) highlight, many important terms relevant to invasion ecology theories include qualities that are open to subjective interpretations. For the present study, it is important to lucidly outline the definition of concepts such as “invasive”, “non-native”, “exotic”, “alien” and “pest” for invasive plants. Several authors have used these terms in proposing schemes for conceptualizing the sequence of events from the introduction to the invasion, but often imprecisely, erroneously or in contradictory ways.

Richardson et al., (2000) defined a set of key definitions for these terms:

- *Alien plants*: are defined as the plant taxa in a specified area whose presence it is due to intentional or accidental introduction due to human activity (synonyms: exotic plants, non-native plants or non-indigenous plants).
- *Invasive plants*: Naturalized plants that produce reproductive offspring, often in very large numbers, at considerable distances from parent plants (approximate scales: > 100 m; < 50 years for taxa spreading by seeds and other propagules; and > 6 m;3 years for taxa spreading by roots, rhizomes, stolons or creeping stems), and thus have the potential to spread over a considerable area.

- *Weeds plants*: (not necessarily alien plants) plants that grow in locations where they are not wanted, and which usually have detectable economic or environmental effects (synonyms: plant pests).
- *Environmental weeds*: are alien plant taxa that invade natural vegetation, usually adversely affecting native biodiversity and/or ecosystem functioning.

When talking about invasive species studies, most of the research focuses upon the impact on ecological and socio-economical systems more than those dealing with management options (Pyšek & Richardson, 2010). Although all of these aspects are closely related, this research focus on the management and occurrence of an invasive species, specifically of Corallita (*Antigonon leptopus*) in Saba, a special municipality of The Netherlands in the Dutch Caribbean. In the following sections, a brief definition and main characteristics of Corallita will be given, as well as information about the island and what is known so far about potential control methods for this plant.

1.1 Corallita

To understand the aim of this project, firstly it is necessary to recognize some traits of the invasive plant. The common name of this plant is Corallita (*Antigonon leptopus*) and is one of the most problematic species in the Dutch Caribbean (Van der Burg et al., 2012). This non-native species, originally from Mexico, was introduced to the Caribbean islands at the beginning of the twentieth century as an ornamental plant due to its beautiful pink flowers and dynamic growth (Berkowitz, 2014; DiTommaso & Burke, 2011). But the plant quickly expanded beyond its area of introduction**.** Once established, it is difficult to eliminate due to it producing many tuberous roots that can propagate vegetatively. Besides, its fruits are light, allowing for effective seed spreading in water (DiTommaso & Burke, 2011). In tropical climates, it has been reported that the plant can usually flower year-round (Raju et al., 2001), making its seed dispersion even easier (See **Box.1** for more information and **Fig. 1**).

It is a stated pest from the South Pacific to Africa and India. In Florida it has been reported as a Category II invasive species (this means that the plant is considered as invasive exotic which has become prevalent, but not yet a threat to local plant communities) and, in its native Mexico, it is considered as a roadside weed (Raju et al., 2001). But is on tropical islands where Corallita has become most persistent and problematic (Ernst & Ketner, 2007).

On St. Eustatius, another special municipality in the Dutch Caribbean, the vine is particularly pervasive, smothering whole areas of vegetation and killing the undergrowth (STENAPA, 2007). Furthermore, due to the underground tubers, it renders whole areas unusable for agriculture and makes reestablishment of nature very difficult (Ernst & Ketner, 2007). In 2014, a study carried out by Berkowitz (2014), estimated that the plant already covers the 33% of the island. The increased abundance of this plant has already prompted the implementation of management efforts in these affected regions.

Box 1. *Main traits of Corallita (GISD, 2018)*

Kingdom	Phylum	Class	Order	Family
Plantae	*Magnoliophyta*	*Liliopsida*	*Liliales*	*Pontederiaceae*

Taxonomic name	*Antigonon leptopus*
Synonyms	*Antigonon cinerascens*, *Antigonon cordatum*, *Antigonon platypus*, *Corculum leptopum*, *Corculum leptopus*
Common names	Antigone (French-Reunion (La Réunion)), antigone à pied grêle (French), chain-of-love (English), confederate vine (English), coral bells (English), coral vine (English), corallita (English), dilngau (Palau), flores ka'dena (Commonwealth of the Northern Mariana Islands), hearts on a chain (English), kadena de amor, liane antigone (French-Reunion (La Réunion)), love-vine (English), Mexican creeper (English), mountain rose (English), queen's jewels (English), rohsapoak (Pohnpei), Sandwich Island creeper (English-India)
Organism type	Perennial vine, climber
Description	*Antigonon leptopus* is robust vine growing to 10m long or more; petioles 0.6-1.5cm long; leaf blades 2.5-7.5 cm long and has a cordate-ovate or triangular shape. The veined is prominent reticulately. The inflorescence is paniculate, the branches bearing flowers in clusters along the rachis. The flowers are bright pink or white, enlarging 1-4 cm long. It can propagate underground via roots or spread above ground by the production of stolons. They persist in the soil by producing tuberous roots.
Habitat description	Prefers dry to moist lowland areas and basic soils, usually grows at ruderal/disturbed urban areas
Main uses	Ornamental
Native range	Mexico, now common in tropical and warm countries
Known introduced range	American Samoa, Anguilla, Bahamas, Bermuda, Cayman Islands, Cook Islands, Dominican Republic, Ecuador, Fiji, French Polynesia, Guadeloupe, Guam, Haiti, Kiribati, Marshall Islands, Mayotte, Micronesia, Federated States Of, Nauru, Netherlands Antilles, Niue, Northern Mariana Islands, Palau, Papua New Guinea, Pitcairn, Reunion, Saint Barthelemy, Samoa, Tonga, United States, United States Minor Outlying Islands and Virgin Islands, U.S.

Figure 1. *Corallita growing in different places in Saba (Autor's own source, 2018)*

1.2 The island of Saba

The Dutch Caribbean consists of the Windward Islands of St. Maarten, Saba, St. Eustatius and the Leeward Islands of Aruba, Bonaire and Curaçao (**Fig.2**). The group of islands are tiny and remote, they have a population fewer than 300.000 inhabitants and a total land area of 800km^2. Nevertheless, they possess rich and diverse fauna and flora, becoming the "hotspot" for biodiversity within the Kingdom of the Netherlands (DCNA, 2014). The islands of Bonaire, Saba and St. Eustatius, commonly referred to as the BES-islands, form a special municipality within the Netherlands. They are located east of Puerto Rico and the Virgin Islands (DCNA, 2014; Dutch Caribbean Legal Portal, 2018).

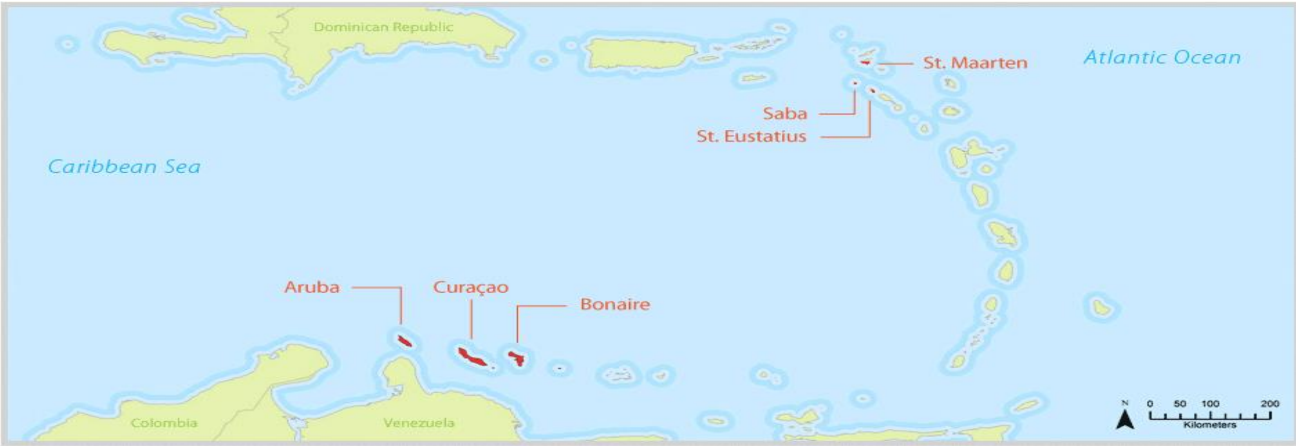


Figure 2. *General view of the Dutch Caribbean islands (DCNA, 2014)*

This research was conducted in Saba (**Fig.3**), a 13km^2 volcanic origin island of approximately 1.947 inhabitants. The island is surrounded by cliffs, thus, there are not permanent beaches on the island and little room for agriculture. Much of the land is covered with lush primary and secondary rainforest that hold an astonishing abundance and diversity of nature. Furthermore, it possesses the highest point in the Kingdom of the Netherlands, Mount Scenery, of about 877 meters high and full of rare and endemic species (DCNA, 2014). Saba's climate is generally dry, with an average of 1,667 mm of rain falling predominantly between August and November, but rainfall varies depending on altitude and exposure to the eastern trade winds. Air temperature varies from maxima exceeding 33ºC during June to August, to less than 25ºC in January-March (World Travel Guide, 2018).

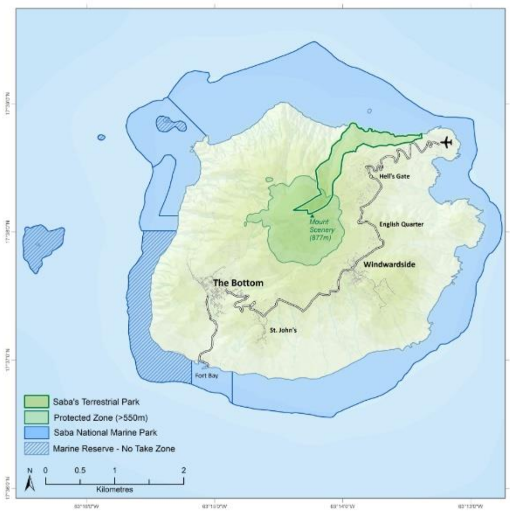


Figure 3. *Map of Saba (DCNA, 2014)*

The diverse ecosystems are a magnet for tourism and nowadays are the most important source of income for the islanders (**Fig.4**). Nature on the islands is unique but it is also fragile. The lack of funding, policy support and adequate spatial planning pose the most significant threats (DCNA, 2014). In addition, the Netherlands is a signatory of the international Convention on Biological Diversity (CBD). This implies that the nation will protect biodiversity on its territory. This includes the protection of natural fauna and vegetation from the negative impact caused by invasive species (Van der Burg et al., 2012).

Figure 4. *Diverse landscapes in Saba. The bottom left picture shows a view of the island's capital (The Bottom) (Autor's own source, 2018)*

1.3 Potential control methods for Corallita

There is an insufficient amount of background literature regarding control methods and management of Corallita. The most complete field research investigating potential control methods and ecology of Corallita was conducted by Joris Ernst and Pieter Ketner in 2007 at St. Eustatius. More recent is the study carried out by Berkowitz (2014), also in St. Eustatius, about the present distribution of Corallita on the same island. So far, what is known about Corallita is its ecology, distribution in part of the Dutch Caribbean islands, the effectiveness of a variety of eradication methods and some suggestions for its control. But further studies are needed on testing the potential effectiveness of more control methods, factors that affect the occurrence of Corallita, an impact assessment of the plant and the development of an adequate control management strategy at the Caribbean.

Ernst and Ketner (2007) have highlighted a group of 7 potential control methods for Corallita. These groups are divided into manual, mechanical, fire, chemical, biological, legal and voluntary actions. After carrying out a one-year pilot project in St. Eustatius, they finally concluded that the most effective way to kill the plant is by using chemicals. The experiment showed that Corallita can be killed with herbicides (such as Garlon and glyphosate-based products). Nevertheless, the authors used very high rates and volumes of these two herbicides. This might not be environmentally or economically acceptable if large areas require treatment (DiTommaso & Burke, 2011).

However, according to the authors, the total eradication of Corallita is no longer possible on St. Eustatius anymore. The species has been on the island for too long and has spread too vigorously. Nevertheless, containment is still feasible to a certain extent, for example at sites where the species is not yet present in large quantities.

1.4 Problem definition and knowledge gap

The Caribbean islands are of great importance to the world's biodiversity, as they house 2.3% of the world's endemic vegetation (Van Andel et al., 2016), and several species of endangered herpetofauna. In the Nature Policy plan for the Caribbean Netherlands (Ministry of Economic Affairs, 2013) invasive species, such as Corallita, are recognized as one of the biggest threats to this delicate biodiversity, thus, invasive species management is of critical importance.

Corallita has several negative impacts on the environment. The plant, being a climber, can overgrow native vegetation and smother it or damage properties by growing into the materials and destroying fences and backyards (Berkowitz, 2014; Ernst & Ketner, 2007). Although various countries have included the species on their list of pests which need control management, no proper control methods have been found so far and there are no initiatives for management strategies in the Caribbean (Ernst & Ketner, 2007).

Since most of the land (around 90%) is privately owned in Saba, the cooperation of landowners in their Corallita practices is essential. There is a need to conduct research to find an effective and sustainable solution that could be used by islanders to properly control the growth of this vine in their own land. Thus, further research into control, ecology, plant phenology and factors regarding growth are needed in order to find an effective solution for the growing Corallita in the Caribbean islands.

One physical factor that is been known to influence plants development is light. Light change not only affects plant morphology (such as plant height or stem and leaf diameter), physiology and microstructure but also has an important impact on production, as it could affect flowering dates and increase or decrease flowers and fruit parts (Dai et al., 2009). It also plays, together with soil moisture, important regulatory roles in seed germination and seedling establishment and survival (Murphy & Lugo, 1986). This is mainly because plant growth and germination require an appropriate light intensity, in other words, an excessively high or low intensity will prevent photosynthesis.

Shade not only influences the amount of light received by plants but also changes other small environmental conditions, such as air and ground temperature, humidity, carbon dioxide (CO_2) concentrations and so on, which are also important factors for plant growth (Zhao et al., 2012).

There are no reported experiments in the past investigating the effects of shade in *Antigonon leptopus*. Nevertheless, some islanders in Saba associate absence of Corallita with the presence of shade (Jetske Vaas, personal communication, February 2018). Therefore, it would be useful to comprehensively understand plant changes that occur when switching between shade and sun exposure in this invasive species, and which shade levels the plant is able to tolerate. This new data could be used for a better understanding of its occurrence and it might be useful as a potential control measure in combination with other management strategies.

1.5 Research aim and scientific relevance

The principal aim of this research was to provide an insight into the effect of shade on *Antigonon leptopus* (Corallita) occurrence by observing the growth and germination rate through a shading experiment. The research was done on a small scale and under relatively controlled circumstances in Saba. Therefore, this study was aiming to provide more information regarding the ecology and occurrence of the plant and its results could be used to complement the current knowledge regarding the potential control methods and occurrence of Corallita.

In parallel to the first aim of the project, a secondary research has been conducted aiming to analyze which control management strategies of Corallita are more appropriate for landowners in Saba. As aforementioned, most of the land in the island is privately owned, therefore, the involvement of landowners is equally important within the Corallita practices. Hence, knowing what the landowners are willing to do to remove the plant, as well as their limitations regarding management strategies, are also important in the process of finding an effective solution.

Thus, this project took an interdisciplinary approach, involving both ecological and social parts of invasive species, towards the challenge of finding an effective method to control Corallita in Saba.

Based on the aims mentioned above, the research focused on answering the following research questions:
For the main aim of the project:

1. What is the effect of shadow on the growth and germination rate of *Antigonon leptopus* (Corallita)?

1.1 What is the effect of shadow on morphological characteristics of Antigonon leptopus (Corallita)?

For the secondary aim of the project:

2. Which *Antigonon leptopus* (Corallita) management strategies are most appropriate for landowners on Saba?

2.1 What limiting factors exist on the household level regarding management strategies?

In order to answer these research questions and to design the experiment, the study has been split into several steps (**Fig. 5**). Those steps are explained in detail in the following section.

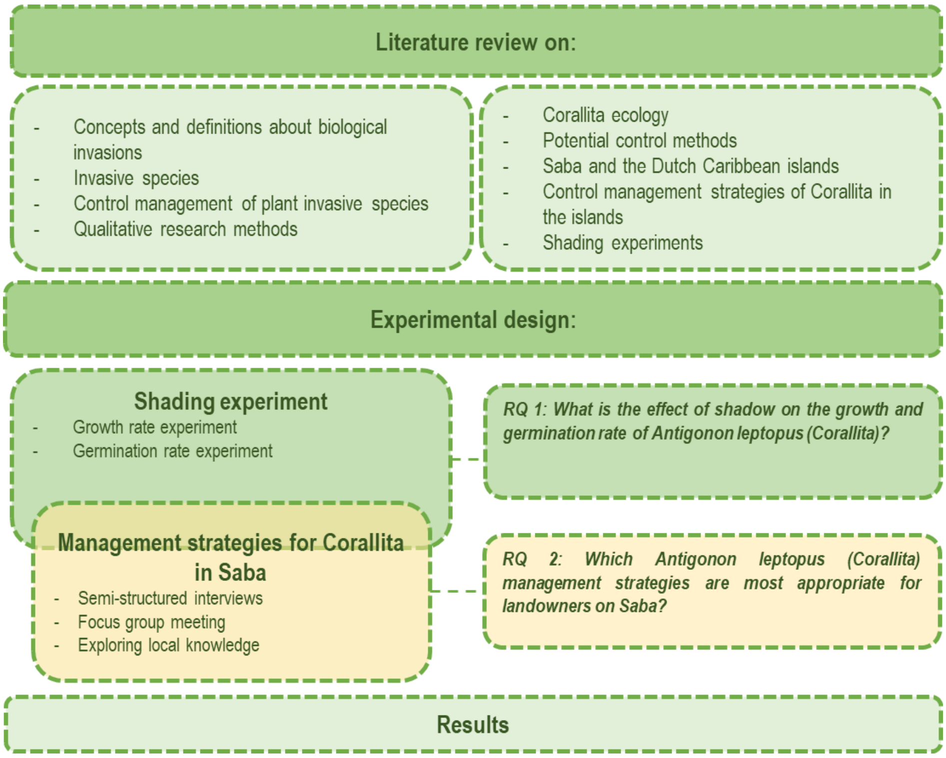


Figure 5. *Research framework (Autor's own source, 2018)*

2. METHODOLOGY

As discussed above, there are several steps that had been undertaken to carry out this research. In the following sections, these steps will be explained.

2.1 LITERATURE REVIEW

To commence with this research project, first, a theoretical background was needed in order to define some key concepts. As mentioned within the "*Potential control methods for Corallita*" section, there is an insufficient amount of existing literature assessing this topic. This research was conducted on a practical level, and the majority of the data needed was primarily obtained in the field using experiments and semi-structured interviews in Saba. Nevertheless, it was important to carry out a literature review about Corallita ecology, studies about invasive plant control methods and invasive plant management.

The objective of carrying out a literature review is to provide enough information to allow to understand the current state of knowledge related to Corallita. Secondly, to be able to design the shading experiment, further research is needed to select the best methodology. For this purpose, a wide range of sources were reviewed with an emphasis on shading and germination experiments developed with other species of plants, due to the lack of information related to Corallita (see Botto et al., 1996; Brenes-Arguedas et al., 2010; Dai et al., 2009; McLaren & McDonald, 2003; Semchenko et al., 2011 and Zhao et al., 2012;).

2.2 SHADING EXPERIMENT

Experiment location

The experiment was carried out in an area of approximately 30m^2 located at The Bottom (Saba). In addition, this terrace was covered by Corallita and free of shade, making it suitable for the purpose of the experiment (**Fig.6**). Due to the presence of wild goats on the island, a fence was needed to protect the area from the goat's grazing. The experimental area was cleared from any form of vegetation, including Corallita, with the exception of 6 plots of 1 by 1 meter.

Figure 6. *Area available for the shading experiment in Saba (Autor's own source, 2018)*

Experimental setup

As aforementioned, the experiment has been designed following the methodology of shading experiments conducted with other plant species and adapting it to Corallita's characteristics. Even though there have not been any specific experiments regarding shading, the work done by J.J.Ernst and P.Ketner (2007) in St. Eustatius was also reviewed since they carried out several projects concerning possible control methods for Corallita. Based on this previous literature research, the experiments were carried out as follows.

2.2.1 Growth rate

Treatments

As the purpose of this experiment was to observe how light change affects Corallita's growth and germination rate, the independent variable, in that case, is the percentage of shade received by the plant.

A total of 48 Corallita hard-branched cuttings of about 10-15cm were collected from different Corallita plants in the surroundings of the experimental area. The stems were selected according to similar age, number of leaves and its length (Ernst & Ketner, 2007), and planted to root in pots of 9,5cm diameter and 6cm tall.

The experiment was performed in pots, and not directly in the field, as the stems are studied as single individuals. The root system of Corallita can propagate broadly underground and the presence of stolons and tubers could influence the results.

The plants were randomly distributed at the research area in 12 blocks (corresponding of 12 replicates/treatment), accordingly to a randomize block design to avoid nuisance factors. The replicates were divided into 4 spectrally neutral shading treatments (see **Appendix A** and **B**): left uncovered (no shading) or covered with neutral density shade cloth (total covered (100%), heavy (60%) and partial shade (20%) were achieved by adding the correspondent number of layers of shade cloth). The control of the experiment corresponds to plants that were left uncovered. Differences in the percentage of light availability for every treatment were measured with a light meter (Digital Luxmeter, HoldPeak) in Lux units (lx) and are reproduced in **Table 1**.

Table 1. *Light availability in Lux units (lx) for every treatment*

Treatment	% shade	Light availability (lx)
1	20% (partial shade)	591x100
2	60% (heavy shade)	236x100
3	100% (total cover)	683x10
Control	0% (no cover)	680x100

The structures with their tops and sides covered by shade cloths were constructed to provide shading treatments, the height of the shade-frame was approximately 300cm high. The soil used to grow the plant was collected from random areas surrounding the experimental zone and mixed it properly before filling the pots.

Measurements

Measurements were taken for a duration of 26 days, beginning on the 10th of April and ending on the 5th of May. It has to be taken into account that the shading treatments employed in this study modified the environment in a similar way to natural shade, which is known to affect wind speed, air temperature and humidity (Semchenko et al., 2011; Zhao et al., 2012). The dependent variables that were quantified in this experiment are morphological parameters, including plant height (cm) and weight (g), leaf number and area (cm^2) of each individual (**Table 2**). Data was recorded 3/4 times per week (Ernst & Ketner, 2007).

To measure the morphological parameters a meter stick was used for the height and area. Height was measured from a mark, set at the first day of measurements, up to the top of the leading shoot. The weight of the plants was measured by removing them from the soil at the completion of the experiment and weighed on a milligrams scale.

Cuttings were recorded as dead if there was no presence of green leaves. Cuttings that were found to be dead were excluded from the measurements.

Table 2. *Shading experiment design for the growing rate of Corallita*

Treatment	Independent variable		Dependent variable	Replicates
Control	% of shade	0% (no cover)	Plant height (cm) Plant weight (g) Nº of leaf Leaf area (cm^2)	12 replicates/treatment
1		20% (partial shade)		
2		60% (heavy shade)		
3		100% (total cover)		
TOTAL				48 plants

In order to get better insights into the growing condition, light intensity was measured every day with the light meter, at the same time and sites where the phenological data was collected.

Soil temperature within the pots, as well in the surrounding soil (covered and noncovered with Corallita) was measured during 4 days. Those temperature readings were measured between 10-11am. The aim of those measurements was to get an insight of the temperature differences between treatments and between the soil covered and noncovered with Corallita.

2.2.2 Germination rate

Treatments

The germination experiment was carried out in the manner as with the growing experiment, with the only difference being the growing method. In this case, seeds were collected directly from different Corallita plants around the island, making sure that the seeds were not empty or dead. This experiment consisted of 2 observation periods, the first one comprised 31 days of observation, starting on the 7th of April until the 7th of May. The second observation period had an extension of 28 days, from the 8th of May until the 4th of June.

As 2 rounds of seeds were incorporated, it was possible to compare the germination rate of 2 different periods. In addition, a greater number of seeds were included as part of the second round to expand the sample size, as it was quite easy to obtain them in the field.

For the first observation period, 80 seeds were planted in plastic plates, 20 for treatment (5 seeds/plate), divided into 4 blocks (see **Appendix B**). A summary of the replicates is shown in **Table 3**. For the second observation period, a total of 120 seeds were planted in plastic pots of 9,5cm diameter and 6cm tall, 30 for treatment, distributed in 10 blocks with 3 seeds/pot (**Table 4**).

Pots were chosen this time instead of plastic plates purely due to practical matters, it was seen that seeds were safer if growing in pots because of the speed of the wind.

Measurements

In that case, the dependent variables measured were the number of seeds that germinated in each treatment and the number of seeds that did not survive. At 2-3 day interval, they were checked for germination. The number of germinated seeds was recorded each time. Of the seeds that survive, the stem height, number and area of leaves and plant weight were measured following the same methodology as in the section before.

Morphological measurements were only obtained from the seedlings germinated at the first round of seeds because of the temporal scope of the experiment.

Table 3 and 4. *Shading experiment design for germination rate of Corallita, observation period 1and 2*

Observation period 1

Treatment	Independent variable		Dependent variable	Replicates
Control	% of shade	0% (no cover)	Nº of surviving seeds Stem height of surviving seeds Nº of non-germinated seeds	20 replicates/treatment
1		20% (partial shade)		
2		60% (heavy shade)		
3		100% (total cover)		
TOTAL				80 seeds

Observation period 2

Treatment	Independent variable		Dependent variable	Replicates
Control	% of shade	0% (no cover)	Nº of surviving seeds Nº of non-germinated seeds	30 replicates/treatment
1		20% (partial shade)		
2		60% (heavy shade)		
3		100% (total cover)		
TOTAL				120 seeds

2.2.3 Data collection and processing

To keep track of all the data and observations during the scope of the experiment, Microsoft Excel was used. The statistical analysis of the results was evaluated by one-way analysis of variance (ANOVA) using SPSS software (*IBM SPSS Statistics 25*). All tests are done using the significance level $\alpha=0.05$.

2. 3 Management strategies for Corallita in Saba

As mentioned, the secondary part of this research was carried out in parallel with the shading experiments. In order to answer the research question 2, data were mostly gathered from semi-structured interviews and a focus group meeting, both performed in Saba, and from informal conversations and observations.

2.3.1 Semi-structured interviews

Data to answer the research question was gathered mostly from semi-structured interviews performed in The Bottom and in Windwardside, the 2 most populated areas in Saba.

A semi-structured interview, in a table format (see **Table 5**), was developed to last around 30 minutes per interviewee. A total of 30 respondents participated in the interview. This system was seen as the best method because the interviewer can refer to a per-studied guide containing a mixture of open and closed questions while having the option to react to responses, improvise and ask for more detailed explanations of the answers (Gray, 2014).

The table used for the interviews was divided into 2 sections. The first section was designed based on choice experiment exercises. In choice experiments, the participants are asked to choose their preferred alternative from several options in a choice set. Each alternative or scenario is described with a number of attributes or characteristics, where the levels of the attributes change from one alternative to the other. An economic value is included, as are other significant features, when presenting each alternative. Thus, when participants make their choices, they implicitly reveal tradeoffs that they are willing to make between the features (Alpízar et al., 2003; Carías Vega & Alpízar, 2011). In this particular case, the table included 2 scenarios:

Scenario 1

This scenario involves a situation where the Government of Saba decides to ban the presence of Corallita on private land.

The participants were asked to choose between 3 different management strategies to get rid of Corallita. This research looked into *more appropriate* management strategies for Corallita that are currently known (see Ernst & Ketner, 2007 and "*1.3 Potential control methods for Corallita*" section). Thus, these management strategies were chosen and divided into chemical, manual and mechanical, and analyzed by looking into the variables of time invested, costs and collateral effects. In other words, the time that the landowner would have to invest to eliminate Corallita, the economic effort that the landowner would have to do, and the collateral effects of using the selected method.

Those 3 variables defining the management strategies are also understood as limiting factors of the same methods. Objectively, it has not been established any kind of quantitative measurement about time invested and costs in terms of Corallita's removal per square meter, therefore, an ordinal scale was used to measure those variables, graded from: very low, low, medium, high and very high. Collateral effects of the management strategies are considered to provide secondary information to the participants, basically focused on potential natural and health impacts.

The aim of presenting this scenario was to achieve an insight of which limiting factor has more importance for the islanders when choosing a management strategy and of what are they willing to do based on their necessities and current resources. Most of the land where Corallita is present in Saba is privately owned, thus, the target group of this research was the landowners. Hence, this study does not include data about which management strategies are *more appropriate* for the island environment, biodiversity or the government.

Based on the previous information, the term "*most appropriate*" was operationalized as the alternative that landowners indicate as the most feasible for them in terms of their current resources.

Scenario 2

This scenario was designed to acquire knowledge about the importance of a fenced land as a limiting factor to control Corallita. As mentioned before, the presence of wild goats at the island requires landowners to fence their land if they want to farm or garden. If there is no fence, the goats would destroy their yards an eat the planted vegetables or fruits. Hence, it was asked to the participants if they would approve a situation where the Government of Saba would pay for fencing their land with two conditions: *(1)*The landowner must get rid of Corallita. However, using an herbicide is not an option since this will pollute the soil too much; *(2)*The owner must use that land to grow vegetables/fruits once Corallita is eradicated.

Land-use, agriculture or gardening are practices that affect the presence and spread of Corallita; otherwise, if landowners do not have a purpose for their yard, they might use it for activities in which Corallita removal is not essential. The practices of individual citizens are thus important to understand as well as how they link with other practices.

The goal of this scenario was to detect if there is any relationship between having a purpose for the land (like gardening or farming; activities that require a fence) and being more efficient getting rid of Corallita.

In the second part of the semi-structured interview, the participants were also asked to answer 4 specific questions:

1. *Do you have Corallita in your yard?*
2. *Did you try to get rid of it?*
3. *Which method did you use?*
4. *Why did you stop?*

The purpose of requesting these questions was to bring to the participants the chance to talk about their individual situation regarding Corallita and to promote an informal conversation to inquire in the local knowledge regarding Corallita practices.

2.3.2 Focus group meeting

Additionally, a focus group meeting was organized at the beginning of June 2018 to talk about Corallita practices, lasting around 60 minutes. A total of 8 landowners participate in the meeting. Gray (2014) defines focus group meetings as an organized discussion among a selected group of individuals with the aim of producing information about their views and to share experiences and knowledge. Indeed, it was also useful to encourage participation of people who do not want to be interviewed on their own and to promote communication between landowners.

Hence, the stakeholder's evening was conducted to gain a range of perspectives about the Corallita problem in Saba, exploring people's opinions, belief and observations (Freeman, 2006). It also provided to local citizens who joined the meeting the opportunity to get involved in the Corallita project on an individual level. Consequently, the attendants could ask questions directly, express their thoughts or ideas about Corallita and know exactly which experiments were performed on the island and for which purpose.

Data gathered from the aforementioned focus group meeting was used to support the findings from the semi-structured interviews and also provide opportunities for the clarifications of responses and posing additional probing questions (Gray, 2014).

2.3.3 Exploring local knowledge

To support the data collection, it was inquired into local knowledge through informal talks with the islanders, writing down perceptions and observations during the entire stay in Saba. Due, in large part, to the collaboration with Jetske Vaas and considering the small dimension and the modest population of the island of Saba, it was possible to meet a great number of people. This was a useful stage for the author to be known by Saba inhabitants and to relate with them. Moreover, it was easier to gain people's interest in participating in the semi-structured interviews and in the focus group meeting as some of the inhabitants already known the author (Gray, 2014).

In addition, to continue increasing access to Saba's society, it was important to gain the empathy of local citizens in terms of Corallita's practices. One way to do that was through the reproduction of some of the control methods that the islanders mentioned using in their own backyard. Investing time and resources on testing those control methods was useful for gaining peoples trust and sympathy, and it was used afterward during the interviews and the stakeholder's evening.

Thus, considering the information gathered from observations and informal talks, as well as practical issues such as time, costs and area available, manual cutting and suffocation of Corallita with a plastic mesh were selected as the more feasible methods to be reproduced.

Experimental setup

The experiment was conducted on a small scale at the rest of the area available for the shading experiment. The treatments were reproduced in 6 plots, fully covered with Corallita, of 1 by 1 meter. In 3 of the plots (A, B and C), a manual cutting of Corallita was replicated, and the regrowth was checked every 7 days. The observation period started on the 9th of April until the 4th of June. In the 3 remaining plots (D, E and F), Corallita plants were covered with a translucent plastic mesh. The experiment started on the 2nd of May and finished 4th of June (see **Appendix B** and **Table 6**).

Only 2 control methods were reproduced mainly due to the extension of the remaining area available to conduct experiments. At least 3 replicates were necessary for every treatment to make it scientifically significant, thus there was only enough space to reproduce 2 methods.

Table 6. *Information regarding the treatments reproduced in the experimental area*

Observation period	Treatment	Plot	Replicates	Area
April 9/June 4	Manual cutting	A/B/C	3 plots/treatment	$3m^2$
May 2/June 4	Translucid mesh	D/F/G	3 plots/treatment	$3m^2$
Total				$6m^2$

2.3.4 Data collection and analysis

The interviews were not recorded because it was perceived that the participants were more comfortable without being registered. Thus, to keep track of all the data, notes were taken during and after the interviews together with the responses. The same procedure was followed for the focus group meeting. Participants from the interviews and the focus group meeting were reminded anonymous and confidential. To address those, they were informed prior to the data gathering on which data will be collected and how it will be used.

Additionally, field notes from observations and perceptions were written down in a notebook during all the stay at the island.

The content of the raw data obtained from the semi-structured interviews, focus group meeting and observations was coded manually following a hybrid process of deductive and inductive coding. Through this procedure, was possible to identify common themes, patterns, repetitions and relationships within the responses and to outline the key points made by participants (Fereday & Muir-Cochrane, 2006). Moreover, Microsoft Excel was used to qualitatively analyze the answers from the semi-structured interviews.

Table 5. *Table used during the semi-structured interviews*

Scenario 1	Description								
Banning Corallita	The Government of Saba decides to fine people if Corallita is seen in their land due to the increasing spread of the invasive plant around the island. The government give some options to the islanders to get rid of it:								
	Management strategies								
	1. Herbicide (Chemical)			**2. Manual**			**3. Mechanical**		
	There is a new herbicide on the market effective against Corallita. It is a cheap option and weakness the plant quickly. However, Corallita will come back again at some point and it exists the risk that it will become resistant to the herbicide. Moreover, it is not selective and, once applied, it will also kill the rest of the surrounding plants.			Another alternative is a manual control of the plant. Cutting the vines all aboveground plant parts is a cheap option to get rid of it. However, it takes more time and effort and it only weakens the plant, so a repetition of the procedure will be needed.			Carrying out a mechanical management might be more expensive than the other two options. Hiring a machine to bulldoze or wreck the entire yard to get rid of Corallita will affect the roots and tubers. Thus, the plant will not come back again. It will be no need to repeat the procedure again as long as the yard is maintained properly, and the owner checks it regularly. If there is presence of Corallita again, pulling it out manually is the best choice.		
	Variables			**Variables**			**Variables**		
	Time invested	**Costs**	**Collateral effects**	**Time Invested**	**Costs**	**Collateral effects**	**Time invested**	**Costs**	**Collateral effects**
	LOW Repetition every 6 months	**MEDIUM**	Corallita might become resistant, and other garden plants will probably not grow well. There is a large chance of polluting nature, killing birds and anoles. Also risk to human health.	**VERY HIGH** Repetition every 10 days	**VERY LOW**	Good exercise to improve health	**VERY LOW** Maintenance after that	**MEDIUM/HIGH**	The yard will be wrecked. Remove of secondary weeds as well

Scenario 2	Description		
Free fencing	The Government of Saba will pay for fencing your land with two conditions. Firstly, the landowner must get rid of Corallita. However, using herbicide is not an option since will pollute the soil too much. The second condition is that the owner must use that land to grow vegetables/fruits.		
	Variables		
	Time invested	**Costs**	**Collateral effects**
	Depending on the control method that the owner chooses	Depending on the control method that the owner chooses	Fresh and cheap vegetables. Improve health and save money in a long term

3. Results

Firstly, results from the shading experiments will be presented, followed by the outcomes obtained from the semi-structured interviews, focus group meeting and observations.

3.1 Shading experiment

Growth rate

After 26 days of observation (from the 10th of April until the 5th of May), no quantitative data could be collected from the growing experiment due to the lack of living cuttings. As aforementioned within the methodology section, saplings were recorded as dead if there was no presence of green leaves, thus, they were dismissed from the measurements.

Corallita can propagate vegetatively, nevertheless, the cuttings planted for the experiment did not develop any root system during the scope of the experiment and they dried before data could be collected.

No qualitative differences were observed between groups either. However, the cuttings that dried the last were those under the heavy shade and total cover treatments. However, in 2 of the replicates for the total cover treatment, it was noticed regrowth of secondary stems from the nodes.

Germination rate

First observation period

After 31 days of observation (from the 7th of April until the 7th of May), the global percentage of germination was 17,5% across all treatments. Overall, 20% corresponds to the no cover treatment, 15% to the partial shade treatment, 25% to the heavy shade treatment and 10% to the total cover treatment (**Fig. 7a**).

The first seeds to germinated corresponded to the partial shade replicates after 10 days of treatment. After 20 days, there was germination in all the treatments, being the heavy shade treatment the one with the maximum number of germinated seeds (5 seeds over 20 planted). By the end of the experiment, the heavy shade treatment was still the one with a major number of survival seeds (**Fig. 7c**).

Seeds germinated from the no cover treatment, together with one seed at the partial shade treatment, were recorded as dead by the end of the experiment.

A one-way ANOVA between subjects was conducted to compare the effect of light availability on the germination rate of Corallita. Although the observed germination percentage on the heavy shade pots was high, there were no significant differences among aspects at the $p<0.05$ level [$F(3,12) = 0,345$, $p = 0,794$].

Second observation period

For the second round of seeds there was no statistically significant difference between the 4 conditions either [$F(3,36) = 0,313$, $p = 0,816$]. After 28 days of observation (from the 8th of May to the 4th of June), 20% of the seeds germinated in total. Concretely, 26,7% correspond to the seeds from the no cover treatment, 16,7% correspond to the partial shade treatment, 20% to the heavy shade treatment and 16,7% to the total cover treatment (***Fig. 7b***).

The first seeds that germinate corresponded to the no cover and partial shade treatments after 18 days from the initial date. Only after 20 days of treatment, there was a sign of germination in all of the treatments, being the no cover treatment the one with a major number of surviving seeds, followed by the heavy shade treatment (**Fig. 7d**).

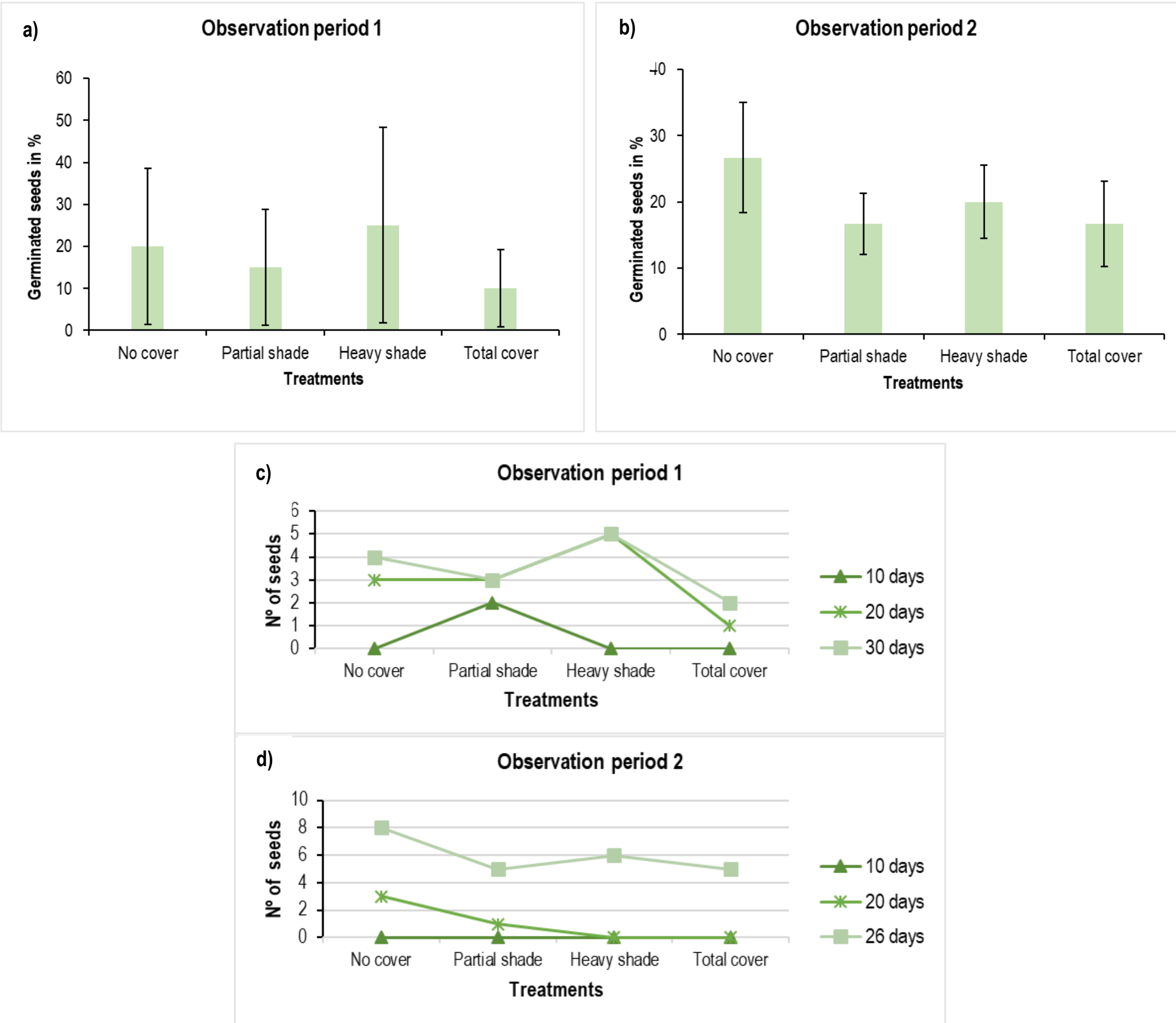


Figure 7. *a and b show the percentage of seeds that germinated in every treatment for the observation period 1 and 2, respectively. Figures* ***c*** *and* ***d*** *corresponds to the number of seeds germinated during the experiment for every treatment (germination after 10, 20 and 30/26 days) for the period 1 and 2, respectively.*

Comparison of the 2 observation periods

The average germination was of 18,5% across all treatments and for the 2 observation periods. In the following graph (**Fig.8**), the percentage of germinated seeds for the 2 observation periods through the whole scope of the experiment is shown. Seeds in the second trial took more time to germinate.

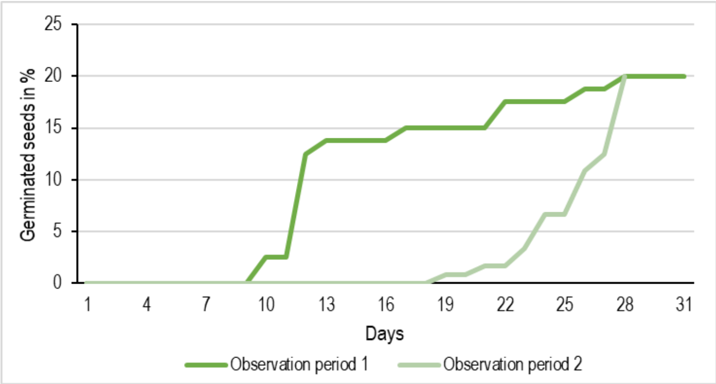


Figure 8. *Percentage of germinated seeds during the experiment, independently of the treatment that they were exposed. Data is shown for both observation periods, 1 and 2*

Seedlings growth rate – *Observation period 1*

Seedlings height

To start off, seedlings height did not differ between the 4 conditions [$F(3,12) = 1,889$, $p = 0,185$] by the end of the experiment. After 31 days of observation (from the 2nd of May until the 4th of June), most of the replicates from the 4 blocks died between the 14th and 24th of May. In regard to the replicates from the no cover treatment, only one, from block 3, reached 4cm of height and was still growing when the observation period finished. The rest stayed between 2,5 and 3cm. The replicates from the partial shade treatment were all dry by the end of the trial. The seedling from block 2 reached 5cm height, the other ones did not grow more than 3cm. For the heavy shade treatment, 3 of the replicates also died between the 14th and the 20th of May, however, replicate from block 2 had a maximum height of 5,7cm. For the total cover treatment, all the replicates died between the 14th and 28th of May. Nevertheless, replicate from block 1 had a maximum height of 6,5cm (**Fig.9**).

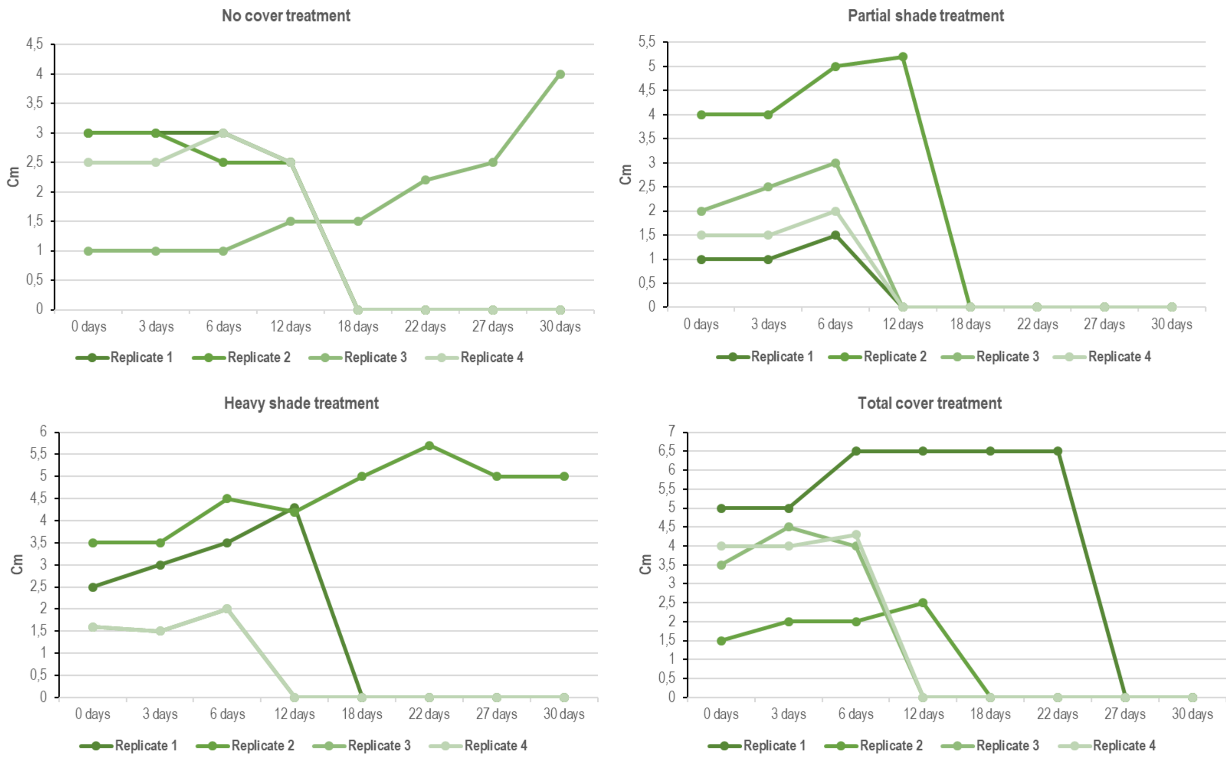


Figure 9. *Seedlings height in cm for every treatment during the scope of the observation period. Height of 0cm corresponds to dead seedlings.*

Leaves number and area

Corallita seeds have a dicot germination, only after 15-18 days they started developing the first leaves. The maximum number of leaves was observed in the replicates from the heavy shade treatment (block 2 and 3), with 4 and 6 leaves respectively by the end of the observation period. Although, there was no a statistically significant effect on the percentage of light availability on the number of leaves at the $p<0.05$ level for the 4 conditions [$F(3,12) = 1,528$, $p = 0,258$].

The area of the leaf was not statistically significant between groups either [$F(3,12) = 0,798$, $p = 0,518$]. At the heavy shade treatment, leaves form replicates form blocks 2 and 3 reached an area of 3 and 4,3cm^2 respectively. For the total cover treatment, leaves form the surviving seedlings had a maximum area of 4 and 4,2cm^2 (blocks 1 and 3). Replicate from the partial shade treatment had a leaf area of 3,7 cm^2 (block 2). Finally, replicates from the no cover treatment reached an area of 4,5 and 4,8cm^2 (block 3 and 4).

Seedlings weight

Seedlings weight was only collected from those that survived until the end of the observation period (4^{th} of June). Overall, 2 replicates from the heavy shade treatment (block 2 and 3), 1 from the total cover treatment (block 4), and 1 from the noncovered treatment from block 3. The weight of the saplings is collected in the following table (**Table 6**).

Table 6. *Weight of the surviving seedlings from the germination experiment*

Block	Treatment	Weight (g)
1	All dead	-
2	60% (heavy shade)	0,17
3	0% (no cover)	0,36
	60%	0,34
4	100% (total cover)	0,07

Soil temperature

The results showed that the average temperature in the pots left uncovered and the soil not covered with Corallita is approximately the same. On the other hand, the soil covered with Corallita had, on average, a similar temperature as in the pots over the heavy shade treatment (**Fig. 10**).

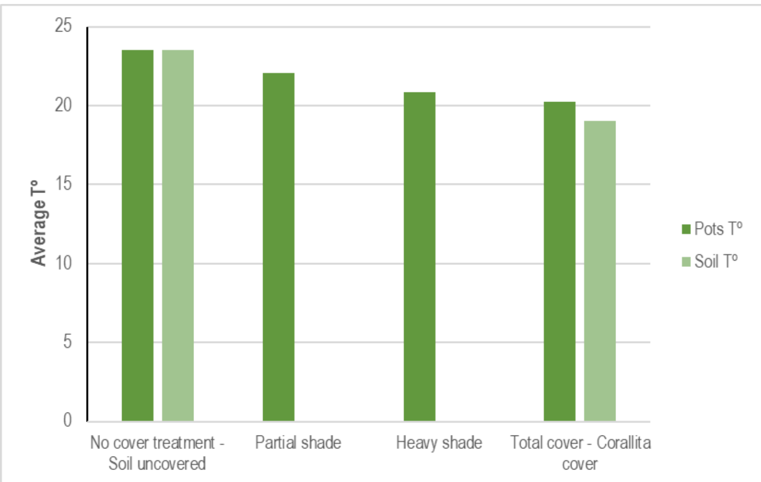


Figure 10. *Soil and pots average temperature*

3.2 Management strategies for Corallita in Saba

Most of the participants (63%) decided to choose a manual management strategy of Corallita over a chemical or mechanical one. Therefore, from this response, it is assumed that landowners are not willing to spend money on the removal of Corallita, even though manual cutting is the alternative that requires more time investment. Some of the respondents also opted for this alternative because they strongly refuse to apply herbicides on their own yard. One of the key variables that drove landowners to select the manual option were the "collateral effects" defined within herbicide alternative (**Table 6**). However, they also refuse the mechanical alternative due to the large expenditure.

The rest of the participants are divided between using a chemical alternative (20%) or using a mechanical force (17%).

The majority of the interviewees who opted for a chemical management strategy placed more importance on the time variable. They were convinced that this is the most effective and fast way to eradicate the plant. Moreover, they claimed that, if the herbicide is applied properly, it will not be damaging to the environment and refused the collateral effects stated within the choice set.

Respondents who opted for a mechanical management strategy discussed that they are willing to spend a "*medium*" or "*high*" amount of money if they only have to apply the control method one time and it is guaranteed that Corallita will not regrowth.

Overall, the economic factor was observed as the most suppressing for landowners in Saba when controlling Corallita. Thus, a manual cutting to remove Corallita is seen as the most appropriate method for them.

When asked for the 2nd scenario, more than half of the participants (57%) supported the idea of receiving free fencing in exchange for controlling Corallita and gardening. Indeed, most of them would like to garden in their land but they cannot afford a fence protecting against the wild goats.

The majority agreed that stimulating landowners to do gardening will help to control the plant, at least on private land. Additionally, most of them stated that bringing back gardening practices on the island would also be beneficial for the well-being, mental and physical health of the inhabitants, as well as favorable in terms of food consumption.

On the other hand, the participants that did not agree with this alternative (43%), strongly disapproved the idea of the government being involved in their private land. They stated they want exclusive rights to choose what they want to do with their land. Moreover, the majority did not agree with the "*must do gardening*" condition. They commented that, during drought periods, they do not want to use water for agricultural purposes.

A few participants mentioned that, even if the government pays for fencing their yard, they should also reimburse the cost of the time invested in getting rid of the plant. Others pointed out that gardening is not a "*classy*" practice, meaning that it is not a well-seen practice within the high-class society. Thus, they prefer to go to the supermarket to buy fruit and vegetables.

All in all, providing financial assistance for fencing inhabitants' private land could be seen as one of the steps for Corallita's control on the island.

In regard to the answers to the specific questions within the semi-structured interview, the responses were quite diverse. All the participants knew about Corallita but not all of them were aware of the threat it represents for the island.

Half of the interviewees had their yard infested with the plant and frustratedly explained how they tried to eliminate it with no success. Matching with the results of the 1st scenario, most of them currently use a manual control strategy, by cutting the plant above the ground when they consider that it is growing too much.

However, the use of herbicides is quite popular among the participants as well. Therefore, it was asked to the participants which kind of herbicide they apply, and the majority mentioned glyphosate-based products such as *RoundUp* or *Gramoxone*.

Only a few used a mechanical force to kill the plant, and only because they had another purpose for the land, such as constructing a swimming pool or buildings.

Some of the respondents also mentioned alternative management strategies that they also apply in their yards.

For example, the owner of *The Bottom Bean Caffe* pores fried oil over Corallita ones every month. He stated that it keeps the plant under control. Other islanders mentioned that they applied gasoline or vinegar directly to the roots and, according to them, this kills the plant.

A few mentioned planting tobacco plants and Panama grass as a biological control for Corallita, although they never tried it by themselves. One of the participants at the focus group meeting commented that pigs can dig up deep under the ground and eat Corallita tubers and suggested that there should be an experimental setup about this method.

The majority of the participants at the focus group meeting discussed finding an eco-friendly way to get rid of the plant. They were also interested in the medicinal or other properties of the plant. Since it is growing almost everywhere on the island, they were also interested in how feasible would be to eat the tubers, make tea from the leaves or sell it somehow to obtain an economic benefit.

Treatments reproduced in the experimental area

Finally, it is also important to mention the results from the treatments that had been reproduced within the plots in the experimental area. In 3 of the plots (A, B and C), where the manual cutting of Corallita was performed, the stems regrowth between 20 and 40cm in only 7 days after the first cutting. After 25 days, they reached a height of approximately 1m. After 25 days, the stems were cut again and measured after 7 days. The regrowth was of about 40cm, but one of the stems already reached 80cm. 5 days later, all the stems measured more than 60cm long, and some of them, more than 1m.

On the other 3 plots (D, E and F), Corallita plants were cut above the ground and covered with a translucent plastic mesh for 30 days. After this period the stems were measured. Overall, the stems did not grow more than 20cm long.

4. Discussion

Shading experiments

The principal aim of this study was to identify the effect of shadow on the germination and growth rate of *Antigonon leptopus*, based on potential modifications of morphological characteristics of the plant and seed survivorship when it is exposed to different percentages of light availability.

Germination rate

It was shown that the average percentage of germination was 18,5% across all treatments and for the 2 observation periods. The no cover and heavy shade treatments were the ones that produced a higher percentage of germinated seeds in both trials. However, within the first observation period, seeds germinated in the no cover treatment did not survive by the end of the experiment. Treatments with a lower percentage of germination were the partial shade and total cover treatments, with a 5-10% difference between the adjacent treatments. The differences in germination rate between the 4 groups are, however, not significant. Thus, these variations are probably due to other factors such as differences in the origin or age of the seeds (Ernst & Ketner, 2007). Furthermore, light availability could indirectly influence the seeds germination via physical factors such as temperature and humidity. By covering the seeds with a shaded mesh, as it was done in this experiment, it altered not only light intensity but also temperature and moisture in a similar way to natural shade (Zhao et al., 2012). Therefore, it is assumed that individuals covered with layers of shade mesh (especially the partial and heavy shade and the total cover treatments) had a higher percentage of soil moisture and lesser rates of soil evaporation and soil temperature.

In fact, pots covered with the heavy shade and total cover treatments had, on average, a soil temperature 3ºC lesser than the ones left uncovered. The soil temperature in the spots where Corallita was present was, on average, of 19ºC. While, in the spots uncovered, the soil temperature was almost 5ºC higher.

It should be noted that the average germination rate across all treatments does not coincide with the results that Ernst & Ketner (2007) obtained. After 11 trials they found that the average germination of Corallita seeds planted in an open space was of 57,5%, much higher than the one reported in this study.

This study shows that germination of Corallita seeds can also occur under shaded conditions, and not only in open spaces. Nevertheless, Ernst & Ketner (2007) stated that under a dense carpet of branches and leaves, seeds barely germinate and soon become molded or eaten. In fact, saplings and seedlings were not frequently found in the field. These observations, in combination with the low germination rates obtained in the current experiment, might lead to the conclusion that seeds play a lighter role in the dispersal of Corallita than vegetative growth through tubers, stems and root cuttings (Ernst & Ketner, 2007).

The effects reported in this study are similar to those reported by researchers using other plant species.

A study performed by Hernández-Oria and colleagues (2017) about the effects of predation, understory light and aspect on germination, seedling establishment and survival on the tropical dry deciduous forest concluded that germination in open spaces decreases. Contrary, shade increased seedling establishment and survival and stated that this process is influenced by the combined effect of both light and soil moisture.

In shaded spaces, soil moisture content and water availability are retained for a longer period (Khurana & Singh, 2004). Thus, the probability of seed hydration is higher. In contrast, the soil in open sites tends to dry more quickly. The main factor driving soil moisture evaporation was, therefore, direct sunlight radiation, which lowered seed-to-seedling transformation (Huante & Rincón, 1998).

Therefore, seedlings of the no cover and partial shade treatments probably died due to desiccation, caused by low soil moisture retention and direct radiation exposure. This effect could be incremented during drought periods, as the desiccation of some of the seedlings coincides with a decrease of rainfall (Ray & Brown, 1995). On the other hand, seeds planted under the heavy shade and total cover treatments had a higher survival rate, possibly because of the reduction of the evaporation rates and higher soil moisture, due to shading.

Following the same reasoning, seeds within the first trial already germinated after 10 days, however, during the second trial, they did it after 18 days. This time difference could be explained due to the lack of rain at the beginning of the second trial, postponing the sprout of the seeds.

Some previous studies also support that environments with high moisture availability and retention, as well as low light levels, allow the successful establishment of seedlings in general (Gerhardt, 1996; Hammond, 1995; Hernández-Oria et al., 2017)

McLaren & McDonald (2003) found similar results when investigating the effects of moisture and shade on seed germination and seedling survival in a tropical dry forest in Jamaica. They reported that seedling survival was lower in unshaded than shaded plots and, in the shaded plots, survival was lower in partial shaded plots than in heavily shaded plots.

Therefore, shaded environments would noticeably improve dry periods survival of some species of seeds (Gerhardt, 1996; McLaren & McDonald, 2003; Morris et al., 2000; Ray & Brown, 1995).

Seedling growth

Morphological parameters measured at the experiment, including seedling height, weight and number and area of leaves were not statistically significant between groups. This shows that the modification of light availability does not necessarily play a role in the growth rate of Corallita seedlings. Most of the replicates in all treatments died after a period of 10 days, mainly due to a significant decrease in rainfall. From those results, it cannot be stated that sites with high moisture and lesser light intensity prolonged survival of Corallita seedlings or enhance their growth.

However, the maximum height was obtained at the total cover treatment, followed by the heavy and partial shade treatments. The replicate with a major number of leaves was the one under the heavy shade treatment, and the ones with the largest leaf area and weight were at the no cover treatment.

Previous researchers obtained diverse results with other plant species. For example, McLaren & McDonals (2013) found that average height of the canopy tree seedlings increased significantly with shading after 6 months and plants under a partially shaded treatment had significantly taller individuals than the unshaded treatments.

Owen (2000) stated that the total dry weight of 2 species of canopy tree seedlings was greater in partial shaded plots than in heavily shaded plots. Semchenko et al. (2011) reported similar results, they concluded that moderate shade had, on average, a net facilitative effect on plant mass. When 90% of natural light was made unavailable, that shaded plants achieved a significantly lower dry mass than unshaded plants. In summary, moderate shade would have a facilitative effect on plant survival and enhance plant growth. Insufficient light may stress plants by limiting photosynthesis, resulting in reduced net carbon gain and plant growth. Conversely, high light levels may damage the photosynthetic apparatus (Larcher, 1995; Ma et al., 2005)

To the contrary, there are also some previous studies that demonstrate that shade can equally suppress growth and seed production of plants. One example is the study conducted by Bello et al. (1995), where the results demonstrated that shade suppresses velvetleaf growth and seed production. Zhao et al. (2012) also obtained that plant height, leaf number, stem diameter, branch number, node number and plant crown width were all higher under sun exposure than under shade when studying the effect of shade on plant growth and flower quality in the herbaceous peony seedlings.

Growth rate

Corallita can propagate underground via roots or spread by the production of stolons. Moreover, it can propagate vegetatively through dispersal of tubers, stem and root cuttings (GISD, 2018). When Corallita cuttings from hard-branches were planted, it was expected them to root on the pots to obtain new individuals for the continuity of the experiment. However, all the samples dried in a short period of time, regardless of the treatment that they were exposed.

The fact that the pots were small and exposed outside made the establishment of the stems impossible, even though the plants were watered twice per day during the first two weeks, additionally to the rainfall. High soil temperatures, due to the size of the pots, and low soil moisture retention were seen as the main drivers of stems mortality.

Management strategies for Corallita in Saba

The secondary aim of this research was to investigate which management strategy to control Corallita is more appropriate for landowners in Saba. The results showed that they are not willing to spend economical resources in the control of Corallita. Thus, a manual control of the plant is seen as the most appropriate, since the costs are roughly zero and is not harmful to the environment, even though this is the most time-consuming strategy.

It has been observed that the involvement of the local government or public bodies could be of great help when encouraging inhabitants to take care of their land. This could be done via funding, legislation or expertise. For example, in terms of subsidies for land fencing or for gardening tools, or by spreading the current knowledge about Corallita, which are the current and potential threats for the island and what every inhabitant can do in an individual level to reduce the spread and growth of the plant. Since the majority of land is privately owned in Saba, the successful management of Corallita requires the cooperation of all the stakeholders in their Corallita practices (Wittenberg & Cock, 2003).

DiTomaso (2000) stated, in his study about invasive weeds in rangelands, that cooperation among private and public entities would increase the potential for early detection and rapid response to new infestations. Effective early detection efforts depend as well on the proper training of landowners. Thus, the understanding of the potential threats of Corallita by landowners could lead to a successful early detection and monitoring of the invasive plant.

Recommendations and future research

Shading experiments

Due to the limited time available to carry out the project, it was not possible to conduct long-term experiments. Furthermore, due to the spatial extension of the experimental area and the restricted amount of materials, the number of replicates and trials had to be reduced. To obtain more data to support the current results, the experiment should be repeated with a higher number of replicates and for a longer period.

Moreover, as plants were grown for only one growing season, most did not reach the reproductive stage. Consequently, shading may have a different effect on plant fitness and plant functioning at the reproductive stage.

Nevertheless, since this experiment was the first one performed in Saba relating Corallita and shade, it was already assumed that it would be subjected to several limitations and challenges.

As aforementioned in previous sections, there is almost no research about how to control Corallita, therefore, there is a lot of room to study. Ernst and Ketner (2007) conducted herbicides effectiveness experiments, however, it is necessary to perform more replicates and extend this current knowledge. Moreover, there are no studies about the possible biological control of Corallita, and this could be a potentially successful area to explore. The goal of biological control is not to eradicate the invasive species but to apply sufficient environmental stress to reduce the dominance of the target plant (DiTomaso, 2000). As some of the participants during the semi-structured interviews mentioned, Panama grass and tobacco plants could have a suppressive effect over Corallita.

Mapping the actual distribution of the plant and performing an impact assessment in Saba, and in the Dutch Caribbean islands in general, will also be necessary to fight this problem (Hulme, 2009).

It would also be interesting to analyze molecular parameters like photosynthetic capacity, light saturation point (LSP), light compensation point (LCP) and apparent quantum yield (AQY) to have a wide range of data of the effect of differences in light intensity in Corallita.

Management strategies for Corallita in Saba

The sample size of the semi-structured interview could have been larger, as it cannot be considered significant if compared with the total population of Saba, as well as the number of focus group meetings performed. Having a Corallita stakeholder's evening more regularly might help to keep track of the new advances in regard to the control of the plant in the island and would help to keep the citizens involved in dealing with this problem. It is important to focus on the level of individual citizens and their practices of land-use that entail the removal or not of Corallita and which policies, in an institutional level, can be adopted.

Nevertheless, it is important to mention that it was challenging to find participants for the semi-structured interviews, mainly due to the lack of interest in the topic or because they did not feel comfortable performing interviews. Due to those reasons, this process was time intensive and slow.

5. Conclusions

In conclusion, the principal approach of this research to the analysis of the effect of shadow on the germination and growth rate of *Antigonon leptopus* allows to determinate that shade does not have a significant effect on its growth and germination. A thorough understanding of the biology and ecology of invasive species, such as Corallita, is necessary for their long-term management. Further research on its invasion dynamics associated with reproduction, growth, spread, resource use, conditions favoring its growth and competitive interactions with other species is, therefore, essential. In addition, it is as well important to be familiar with the characteristics of the ecosystem where it is established.

In regard to the second approach to identify the most appropriate control method for landowners in Saba, is concluded that the economic factor is the most suppressing when controlling the plant. Thus, a manual control method is currently seen as the most appropriate for landowners. Nevertheless, it is important to remember that a coordinated effort among interested parties, including the general public, private and public landowners, the government and environmental organizations can lead to a more effective management strategy of Corallita.

ACKNOWLEDGMENTS

First of all, I would like to thank Jetske Vaas for introducing me to Corallita and to the beautiful island of Saba, as well for their continuous help in the data collection, making contacts and moral support. My appreciation and gratitude also go to my supervisor, prof. dr. Max Rietkerk, for guiding and motivating me through the whole project.

My gratitude as well to the Saba Conservation Foundation staff to lend me some tools for my experiment and including me in their group.

I would also like to thanks to all the people from Saba who participated in the focus group meeting and interviews, their time and contribution to the project are highly appreciated.

Lastly, I would like to thank my wonderful family and *amigos* for their endless love and unlimited patience. This accomplishment would not have been possible without them.

REFERENCES

Alpízar, F., F. Carlsson, and P. Martinson. 2003. Using Choice Experiments for Non-market Valuation. *Economic Issues*, Vol. 8(1): 83–110.

Bellard, C., Cassey, P., & Blackburn, T. (2016). Alien species as a driver of recent extinctions. *Biology Letters*, Vol. 12, 12

Bello, I., Owen, M., & Hatterman-Valentp, H. (1995). Effect of Shade on Velvetleaf (Abutilon theophrasti) Growth, Seed Production, and Dormancy. *Weed Technology*, Vol. 9(3), 452-455. doi:10.1017/S0890037X00023678

Berkowitz, B. (2014). The state of *Antigonon leptopus* (Corallita) on St Eustatius in 2014. Unpublished Report. STENAPA, Gallows Bay, St. Eustatius.

Blackburn, T. M., Pyšek, P., Bacher, S., Carlton, J. T., Duncan, R. P., Jarošík, V., & Richardson, D. M. (2011). A proposed unified framework for biological invasions. *Trends in Ecology and Evolution*, Vol. 26(7), 333–339. https://doi.org/10.1016/j.tree.2011.03.023

Botto, J. F., Sanchez, R. A., Whitelam, G. C. & Casal J. J. (1996). Phytochrome A Mediates the Promotion of Seed Germination by Very Low Fluences of Light and Canopy Shade Light in Arabidopsis. *Plant Physiology*, Vol. 110 (2), 439-444

Brenes-Arguedas, T., Roddy, A.B., Coley, P.D. & Kursar, T. (2011). Do differences in understory light contribute to species distributions along a tropical rainfall gradient? *Oecologia*. Vol. 166:443. https://doi.org/10.1007/s00442-010-1832-9

Carías Vega, D. & Alpízar, F. (2011). Choice Experiments in Environmental Impact Assessment. The Case of the Toro 3 Hydroelectric Project and the Recreo Verde Tourist Center in Costa Rica. *Environment for Development. 11-04*

Colautti, R., & MacIsaac, H. (2004). A neutral terminology to define 'invasive' species. *Diversity and Distributions*. Vol. 10, 2, 135-141. https://doi.org/10.1111/j.1366-9516.2004.00061.x

Dai, Y.J., Shen, Z.G., Liu, Y., Wang, L.L., Hannaway, D. & Lu, H.F. (2009). Effects of shade treatments on the photosynthetic capacity, chlorophyll fluorescence, and chlorophyll content of Tetrastigma hemsleyanum Diels et Gilg. *Environ. Exp. Bot.*, Vol. 65, 177-182

DiTomaso, J. (2000). Invasive weeds in rangelands: Species, impacts, and management. Weed Science, Vol 48(2), 255-265. doi:10.1614/0043-1745(2000)048[0255:IWIRSI]2.0.CO;2

DiTommaso A., & Burke, J. (2011). Corallita (*Antigonon leptopus*): Intentional Introduction of a Plant with Documented Invasive Capability. *Invasive Plants Science and Management*, Vol. 4 (3), 265-273.

DCNA, Dutch Caribbean Natural Alliance, (2014). Dutch Caribbean Islands. Retrieved 20 February 2018, from: http://www.dcnanature.org/islands/

Dutch Caribbean Legal Portal, (2018). Retrieved February 2018, from: http://www.dutchcaribbeanlegalportal.com/about-us/the-dutch-caribbean

Ehrenfeld, J. G. (2010). Ecosystem consequences of biological invasions. *Annual review of ecology, evolution, and systematics*, Vol. 41, 59-80.

Ernst, J. J., & Ketner, P. (2007). Final Report: Corallita pilot project: St. *Eustatius, Netherlands Antilles. St. Eustatius, Netherlands Antilles: Published by the authors*.

Ewel, J. J., O'dowd, D. J., Bergelson, J., Daehler, C. C., D'antonio, C. M., Gómez, L. D., & Hughes, C. E. (1999). Deliberate introductions of species: research needs: Benefits can be reaped, but risks are high. *BioScience*, Vol. 49(8), 619-630.

Fereday, J., & Muir-Cochrane, E. (2006). Demonstrating Rigor Using Thematic Analysis: A Hybrid Approach of Inductive and Deductive Coding and Theme Development. *International Journal of Qualitative Methods*. Vol.5 (1). Retrieved 7 July 2018, from: http://www.ualberta.ca/~iiqm/backissues/5_1/pdf/fereday.pdf

Freeman, A.M. III. (1993). *The Measurement of Environmental and Resource Values: Theory and Methods*. Washington, DC: Resources for the Future.

Gaertner, M., Den Breeyen, A., Hui, C. & Richardson, M. (2009). Impacts of alien plant invasions on species richness in Mediterranean-type ecosystems: a meta-analysis. *Progress in Physical Geography: Earth and Environment*, Vol. 33, 3, 319 – 338

Gerhardt, Karin. (1996). Germination and development of sown Mahogany (Swietenia macrophylla King) in secondary tropical dry forest habitats in Costa Rica. *Journal of Tropical Ecology*. Vol. 12, 275 - 289. 10.1017/S0266467400009457.

GISD, Global Invasive Species Database, (2018). Species profile: *Antigonon leptopus*. Retrieved 3 February 2018, from: http://www.iucngisd.org/gisd/species.php?sc=203 on 03-03-2018

Gray, D.E (2014). *Doing Research in the Real World*. SAGE Publications

Hammond, D. S. (1995). Post-dispersal seed and seedling mortality of tropical dry forest trees after shifting agriculture, Chiapas, Mexico. *Journal of Tropical Ecology*, Vol. 11(02), 295-313. doi:10.1017/s0266467400008762

Hejda, M., Pyšek, P. & Jarošík, V. (2009). Impact of invasive plants on the species richness, diversity and composition of invaded communities. *Journal of Ecology*, Vol. 97, 393 - 403. 10.1111/j.1365-2745.2009.01480. x.

Hellmann, JJ., Byers, JE., Bierwagen, BG., & Dukes, JS. (2008). Five potential consequences of climate change for invasive species. *Conserv Biol*, Vol. 22(3), 534-43. doi: 10.1111/j.1523-1739.2008.00951. x.

Hernández-Oria, J. G., Hawkins, R. I., Tostado, E. C., & Barradas, V. L. (2017). Early establishment and survival of the neotropical dry deciduous forest tree Lysiloma microphyllum from mountainous Bajio Queretano, Mexico. *Journal of Tropical Ecology*, Vol. 33(03), 213-227. doi:10.1017/s0266467417000116

Hulme, P. (2009). Trade, transport and trouble: managing invasive species pathways in an era of globalization. *Journal of Applied Ecology*, Vol. 46, 1, 10-18

Khurana, E., & Singh, J. (2004). Germination and Seedling Growth of Five Tree Species from Tropical Dry Forest in Relation to Water Stress: Impact of Seed Size. *Journal of Tropical Ecology*, Vol. 20(4), 385-396. Retrieved from http://www.jstor.org/stable/4091851

Larcher, W. (1995). *Physiological Plant Ecology. Ecophysiology and Stress Physiology of Functional Groups*. Springer, Berlin, Heidelberg, New York.

Liao, C., Peng, R., Luo, Y., Zhou, X., Wu, X., Fang, C. & Li, B. (2008). Altered ecosystem carbon and nitrogen cycles by plant invasion: A meta-analysis. *New Phytologist*, Vol.177(3), 706-714.

Ma, X., Song, L., Yu, W., Hu, Y., Liu, Y., Wu, J., & Ying, Y. (2015). Growth, physiological, and biochemical responses of *Camptotheca acuminata* seedlings to different light environments. *Frontiers in Plant Science*, 6. doi:10.3389/fpls.2015.00321

McLaren, K. & McDonald, M.A. (2003). The effects of moisture and shade on seed germination and seedling survival in a tropical dry forest in Jamaica. *Forest Ecology and Management*, Vol. 183, 1–3, 61-75

Millennium Ecosystem Assessment, 2005. Retrieved 10 February 2018, from: https://www.millenniumassessment.org/en/index.html

Ministry of Economic Affairs, 2013. Retrieved 3 March 2018, from: https://www.government.nl/ministries/ministry-of-economic-affairs-and-climate-policy

Morris, M. H., Negreros-Castillo, P., & Mize, C. (2000). Sowing date, shade, and irrigation affect big-leaf mahogany (*Swietenia macrophylla King*). *Forest Ecology and Management*, Vol.132(2-3), 173-181. doi:10.1016/s0378-1127(99)00224-8

Murphy, P.G, & Lugo, A.E. (1986). Ecology of Tropical Dry Forest. *Annual Review of Ecology and Systematics*, Vol. 17, 67-88. https://www.jstor.org/stable/2096989?seq=1#page_scan_tab_contents

Osunkoya, O., Ash, J., Hopkins, M., & Graham, A. (1994). Influence of Seed Size and Seedling Ecological Attributes on Shade-Tolerance of Rain-Forest Tree Species in Northern Queensland. *Journal of Ecology*, Vol. 82(1), 149-163. doi:10.2307/2261394

Owen, A.J.M. (2000). An investigation of the seedlings of four tropical dry limestone scrub forest tree species, Hellshire Hills, Jamaica. M.Sc. dissertation, University of Wales, Bangor, UK, p. 125

Pejchar, L., & Mooney, H. A. (2009). Invasive species, ecosystem services and human well-being. *Trends in ecology & evolution*, Vol. 24(9), 497-504

Pimentel, D., S. McNair, J. Janecka, J. Wightman, C. Simmonds, C. O'Connell, E. Wong, L. Russel, J. Zern, T. Aquino & T. Tsomondo. (2001). Economic and environmental threats of alien plant, animal, and microbe invasions. *Agriculture, Ecosystems and Environment*, Vol. 84, 1–20

Powell, K., Chase, J. & Knight, T. (2011). A synthesis of plant invasion effects on biodiversity across spatial scales. *American Journal of Botany*, Vol. 98, 3, 539-548. https://doi.org/10.3732/ajb.1000402

Pyšek, P., & Richardson, D. M. (2010). Invasive Species, Environmental Change and Management, and Health. *Annual Review of Environment and Resources*, Vol.*35*(1), 25–55. https://doi.org/10.1146/annurev-environ-033009-095548

Raju, A. J. S., Raju, V. K., Victor, P., & Naidu, S. A. (2001). Floral ecology, breeding system and pollination in *Antigonon leptopus* L. (Polygonaceae). *Plant Species Biology*, Vol. 16(2), 159–164.

Randomized Block Design: Two-way MANOVA (2018). Retrieved 5 March 2018, from "The Pennsylvania State University website": https://onlinecourses.science.psu.edu/stat505/node/171

Ray, G.J. & Brown, B.J. (1995) Restoring Caribbean dry forests: Evaluation of tree propagation techniques. *Restoration Ecology,* Vol. 3:86–94

Richardson, D. M., Pyšek, P., Rejmánek, M., Barbour, M. G., Dane Panetta, F., & West, C. J. (2000). Naturalization and invasion of alien plants: Concepts and definitions. *Diversity and Distributions*, Vol. 6(2), 93–107. https://doi.org/10.1046/j.1472-4642.2000.00083.x

Rincón, E., & Huante, P. (1993). Growth responses of tropical deciduous tree seedlings to contrasting light conditions. *Trees*, Vol. 7(4). doi:10.1007/bf00202074

Schlaepfer, A.M., Sax, D.V. & Olden, J.D. (2011). The Potential Conservation Value of Non-Native Species. *Conservation Biology*, Vol. 25, 3, 428-437

Semchenko, M., Lepik, M., Götzenberger, L., & Zob, K. (2011). Positive effect of shade on plant growth: amelioration of stress or active regulation of growth rate? *Journal of Ecology*, Vol 100 (2), 459-466

Shao, Q., Wang, H., Guo, H., Zhou, A., Huang, Y., Sun, Y., & Li, M. (2014). Effects of Shade Treatments on Photosynthetic Characteristics, Chloroplast Ultrastructure, and Physiology of Anoectochilus roxburghii. *PLoS ONE*, Vol.9(2), e85996. http://doi.org/10.1371/journal.pone.0085996

STENAPA, 2018. Retrieved 2 February 2018, from: http://www.statiapark.org/

Van Andel, T., van der Hoorn, B., Stech, M., Arostegui, S. B., & Miller, J. (2016). A quantitative assessment of the vegetation types on the island of St. Eustatius, Dutch Caribbean. *Global Ecology and Conservation*, Vol. 7(Supplement C), 59–69. https://doi.org/10.1016/j.gecco.2016.05.003

Van der Burg, W., De Freitas, J., Debrot, A., & Lotz, L. (2012). Naturalised and invasive alien plant species in the Caribbean Netherlands: status, distribution, threats, priorities and recommendations: report of a joint Imares/Carmabi/PRI project financed by the Dutch Ministry of Economic Affairs, Agriculture & Innovation. *Plant Research International*, Business

Unit Agrosystems Research. *Plant Research International*. Retrieved from: https://www.wur.nl/en/Publication-details.htm?publicationId=publication-way-343232303939

Vilà, M., Espinar, J., Hejda, M., Hulme, P., Jarošík, V., Maron, J., Pergl, J., Schaffner, J., Sun, Y. & Pyšek, P. (2011). Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities and ecosystems. *Ecology Letters*, Vol. 14, 7, 702-708

Vilà, M., Tessier, M., Suehs, C., Brundu, G., Carta, L., Galanidis, A., Hulme, P. (2006). Local and Regional Assessments of the Impacts of Plant Invaders on Vegetation Structure and Soil Properties of Mediterranean Islands. *Journal of Biogeography*, Vol. 33(5), 853-861. Retrieved from: http://www.jstor.org/stable/3838496

Wilcove, D. S., Rothstein, D., Dubow, J., Phillips, A., & Losos, E. (1998). Quantifying threats to imperiled species in the United States. *BioScience*, Vol. 48(8), 607-615.

Wittenberg, R., & Cock, M. J. (2003). *Invasive alien species: A toolkit of best prevention and management practices*. Wallingford Oxon UK: CABI Publishing.

Wood, A.J. & Roper, J. (2000). A Simple and Nondestructive Technique for Measuring Plant Growth and Development. *American Biology Teacher*, Vol. 62, 3, 215-1

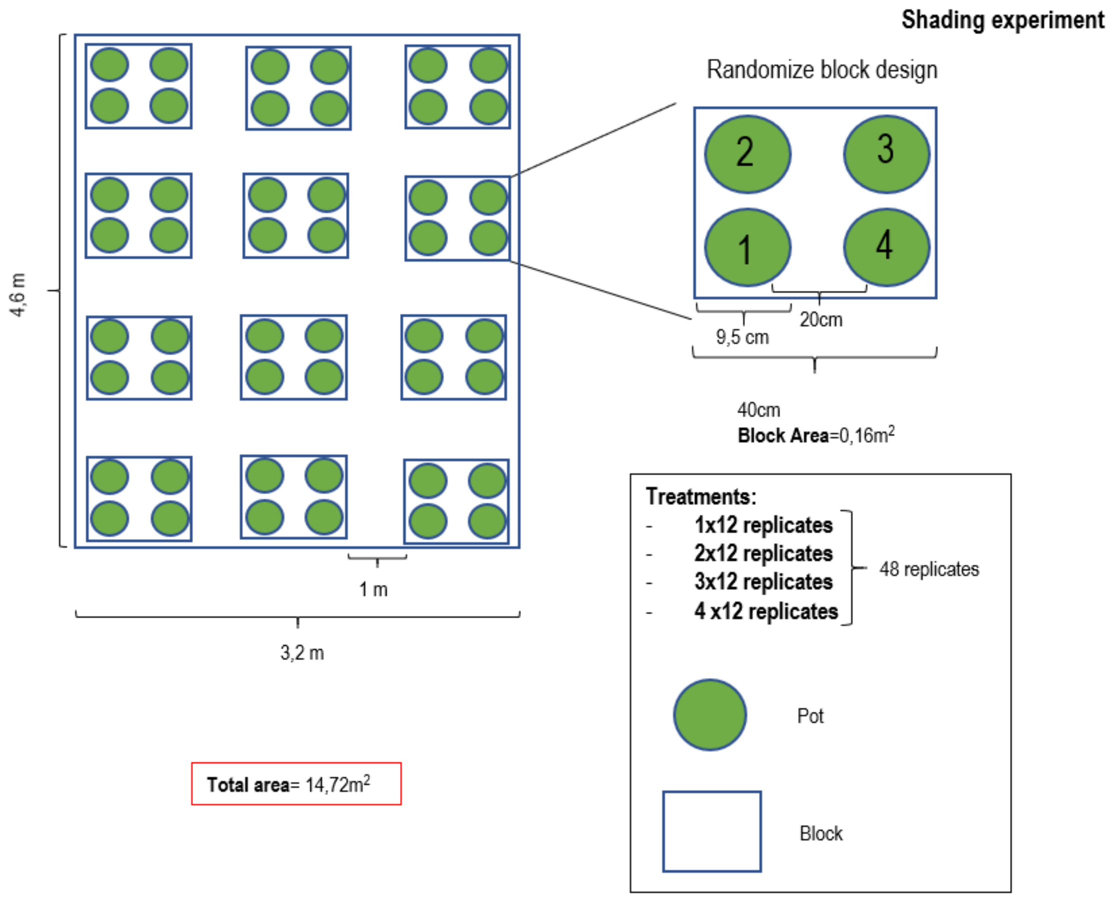
Word Travel Guide. (2018). Saba weather, climate and geography. Retrieved 1 August 2018, from: https://www.worldtravelguide.net/guides/caribbean/saba/weather-climate-geography/

Zhao, D., Hao, Z., & Tao, J. (2012). Effects of shade on plant growth and flower quality in the herbaceous peony (Paeonia lactiflora Pall). *Plant Physiology and Biochemistry*, Vol. 61, 187-196.

APPENDICES

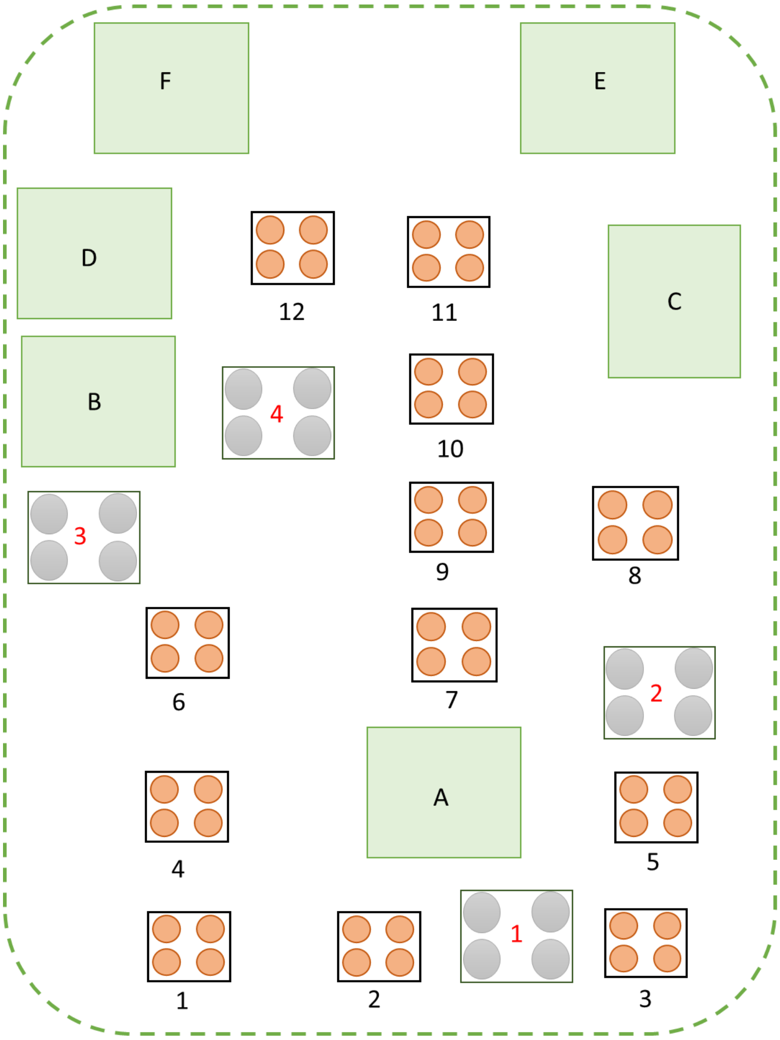
A. Shading experiment - Blocks distribution

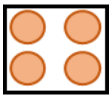
Adaptation of the distribution of the blocks in the field for the growth and germination experiment. The green circles represent the pots where Corallita was planted. The blue rectangles correspond to blocks. Within every block, 4 pots were distributed, corresponding to the 4 treatments (1= partial shade treatment, 2=heavy shade treatment, 3=total cover and 4= uncovered). Treatments were distributed randomly in every block.



B. Experiments distribution

Distribution of the blocks for the growing and germination experiment (observation period 1 and 2) and for the plots where the manual cutting (A, B and C) and the translucent plastic mesh (D, E, F) were applied.



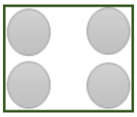


Growth rate experiment and germination rate experiment – Observation period 2:

- Growth rate: 12 blocks and 48 pots (4pots/block)
- Germination rate – Observation period 2: 10 first blocks and 40 pots (3seeds/pot)

Exploring local knowledge:

- Plots A, B and C: Manual cutting
- Plots D, E and F: Translucent mesh



Germination rate experiment – Observation period 1: 4 blocks and 16 plates (5seeds/plate)

Area experiment: $30m^2$

Area plots (A to F): $1x1m^2$

Area blocks: $0,16m^2$