The EAI-Project

Understanding long-term effects of land-use change on biodiversity, ecosystem services and farmer socio-economy on the Brazilian cocoa coast.

The **E**cological **A**ssessment **I**nitiative (**EAI-Project**) is a scientific cooperation project of **Westlake University (WU)**, the **Universidade Estadual de Santa Cruz (UESC)** and **AMAP**, which aims to quantify the long-term effects of land use changes on biodiversity and its socio-economic consequences for cocoa farmers in the Cabruca agroforestry system (cocoa forest) of Brazil. The results will be used to develop recommendations for action for local stakeholders such as cocoa farmers and production cooperatives. The aim is to tackle land use change towards intensive cultivation methods (pasture farming, monocultures, higher use of pesticides). The long-term goal is to secure the income of cocoa farmers through ecological intensification methods of cultivation, and thus preserve biodiversity and ecosystem services of the region. **The initial phase** of the Project was carried out from 2022 to 2024. **In 2026 the start of the second phase is planned**.

AMAP is a Brazilian environmental organization dedicated to the conservation of the Mata Atlântica, the Brazilian Atlantic Rain forest. The golden-headed lion tamarin is as a flagship species of the region the symbol of our mission. AMAP contributes to the conservation of the Mata Atlântica and its biodiversity through species conservation projects, forest restoration and research projects that promote biodiversity conservation. The base of our activities in the region is the Fazenda Bom Pastor not far from the Almada River.

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The EAI project is based on basic biodiversity monitoring in six different landscape types (forest types, caburca types and open areas) on the cocoa coast of southern Bahia. AMAP provides the personnel, logistics and infrastructure for the monitoring, while the scientific expertise is provided by the project partners. The actual research projects are integrated into the basic monitoring. Thus the EAI project is designed as a platform for cooperation with international research partners whose projects contribute to the conservation of biodiversity in the region. The results will provide recommendations on best agro-ecological practices for sustainable cocoa production, biodiversity conservation, and ultimately to improve farmer livelihoods.

I. Project framework

The Atlantic rain forest, the Mata Atlântica, is one of Brazil's six major biomes, extending along the Atlantic coast of South America across tropical and subtropical climates and over a wide range of elevations. This geographic variability makes the Mata Atlântica one of the most species-rich biodiversity hotspots in the world (Myers et al. 2000; Shi et al. 2005). In particular, Brazil's rapid population growth during the 20th century greatly reduced the Mata Atlântica. Two-thirds of Brazil's population, over 125 million people, now live within the original extent of the Mata Atlântica, which includes the mega cities of Sao Paulo and Rio de Janeiro. As a result, the Mata Atlântica has declined by approximately 90% and the remaining relict areas are highly fragmented (Ribeiro et al. 2009; Rezende et al. 2018). Biodiversity decline cannot be prevented by designating protected areas (Bawa et al. 2004). While these interventions are important, they are entirely insufficient in a landscape whose natural areas are now dominated by a broad range of anthropogenic uses.

In the state of Bahia, on the cocoa coast of Brazil, it is only due to the unique form of cocoa cultivation that the biodiversity of the Mata Atlântica has been preserved (Schroth & Harvey 2007; Cassano et al., 2009). In this traditional form of forestry, cocoa cultivation occurs as an understory in the original rain forest, whose canopy is preserved. These cocoa forests, called cabrucas, enabled the preservation of biodiversity and represent a counter concept to the cocoa monocultures of West Africa. Cabrucas form the matrix in the local mosaic of different forms of use, in which, for example, primary and secondary forest fragments but also, for example, pastures are embedded. They function as corridors between habitats for native fauna or are used as habitat themselves (Faria et al., 2006, 2007, Sambuichi 2006, 2007). The golden-headed lion tamarins (*Leontopithecus chrysomelas*), which are endemic and highly endangered here, have only been able to survive through this farming practice (Holst et al. 2006; Oliveira et al. 2009).

Cabrucas function as corridors between habitats for native fauna or are used as habitat themselves.

Cocoa cultivation is the region's most important source of income and Bahia's most important commodity for export. However, Brazil has been a niche producer of cocoa since the decline of its cocoa production in the 1980s. Its world market share shrank to 3.5%. Yet cacao production in the traditional cabruca agroforestry system has many advantages over cultivation in monocultures. Cabrucas exhibit strong resilience to environmental variability such as droughts, and with appropriate agro-ecological management, they are suitable to address climate change (Colombo & Joly, 2010; Gateau-Rey et al., 2018). In addition, ecosystem services such as soil fertility, erosion control, groundwater and CO_2 storage are preserved (Novais et al., 2016; Schroth et al., 2015). These benefits are offset by a lower yield per hectare compared to monocultures, which, since the collapse of cocoa prices, has left the region in a difficult position on the world market. This has led to a variety of land use changes in recent decades, such as a switch to cattle ranching or to the cultivation of more profitable crops such as rubber and eucalyptus (Oliveira et al., 2009; Schroth & Ruf 2013). In general, economic pressure led to an intensification of cocoa cultivation. The most widespread practices include increasing cacao tree cover, reducing shade trees, replanting fewer tree species, especially nitrogen-fixing and fast-growing trees, and increasing the use of agro-chemical products (Cassano et al. 2011; Rolim & Chiarello 2004). Such land use changes lead to a slow loss of original biodiversity and complexity of the cabruca (Delabie et al., 2007; Faria et al., 2006; Grelle et al., 2005; Jared et al., 2015; Sambiuchi et al., 2012). This also decreases agro-economic benefits, such as ecosystem services and resilience to environmental variability (Colombo & Joly, 2010), which will be crucial, especially in light of climate change (Gateau-Rey et al., 2018).

II. Objectives

In order to counteract losses of biodiversity and ecosystem services due to land use changes, these changes have to be proven and quantified. Then, the socio-economic consequences can be determined and recommendations for actions can be developed to enable biodiversity conservation. Therefore, the methodology of monitoring - observing specific parameters of an ecosystem to detect changes over time, for example - is a key element. However, monitoring methods are very labor-intensive, require a high degree of specific expertise, and are thus associated with high costs. In university practice, monitoring is often only possible over a short period of time or with a small number of study plots, which often severely limits the scientific possibilities.
In the EAI Project, these problems are solved on the one hand by exceptional cooperation and on the other hand by more advanced monitoring methods. This will reduce costs and increase the precision of data collection, allowing for more comprehensive monitoring. The Ecological Assessment Initiative (the EAI-Project) aims to quantify the long-term effects of land use change on biodiversity and its socio-economic consequences in the cabruca agroforestry system. The results will be used to develop recommendations for action for local actors, such as cocoa farmers and production cooperatives. For this purpose, a long-term monitoring system will be set up, the project design of which enables AMAP-Brazil, as a local environmental protection actor, to carry out the data collection.

Fazenda Bom Pastor, headquarter of AMAP Brazil and a typical cocoa farm, is situated within the project area.

The study sites are located in the project area of AMAP, on the Fazendas Bom Pastor, Santa Rita, Julia and neighboring farms. Personnel (research assistants) and logistics (vehicles, equipment, accommodation) to carry out the project will be provided by AMAP Brazil. The scientific expertise is provided by the SASE Lab at Westlake University led by Prof. Thomas C. Wanger, with Dr. Manuel Toledo-Hernández, Post Doc at SASE Lab, assuming the scientific coordination of the EAI Project. This cooperation makes the implementation of long-term monitoring possible. The EAI project has the character of a platform, providing cooperation partners (universities or NGOs) with personnel and infrastructure, thus enabling them to carry out further scientific projects that contribute to the conservation of the biodiversity of the Mata Atlântica.

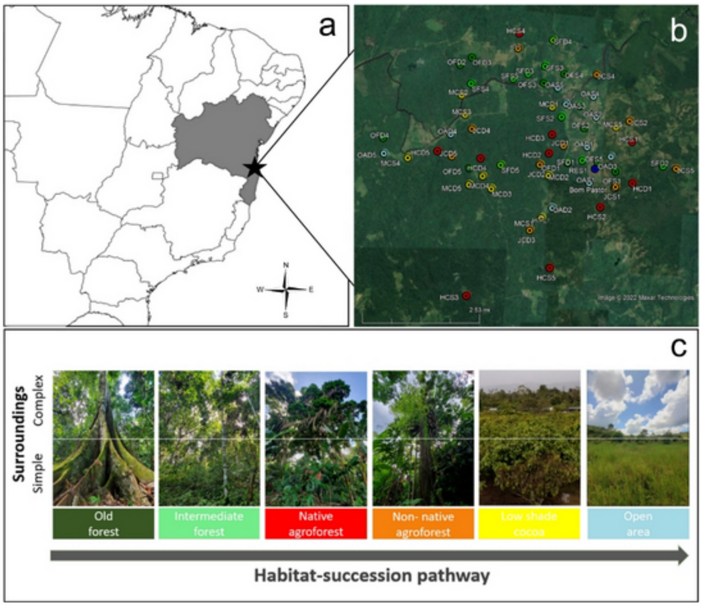
The first phase of the project will run over a three-year period and has the following objectives:

- To understand how land use changes affect tree diversity and the impact on ecosystem services.
- Estimate how pollination, pest infestation, carbon sequestration and thereby cocoa yield evolve along a gradient of land use intensity in cabrucas
- To develop a predictive model for the environmental and socio-economic factors of boom and burst cycles of cacao production in Bahia to make predictions for sustainable land use at the regional level.
- To develop recommendations for regional stakeholders, with the aim of establishing agro-economic practices that serve biodiversity conservation, sustainable cocoa production and adaptation to climate change.

III Project implementation

3.1 Project area and establishment of the research plots

To implement the EAI project, AMAP has hired three research assistants since April 2022. Dr. Manuel Toledo-Hernández is responsible for the coordination and supervision of the assistants on site.
The project area is located in the south of Bahia, about 30km west of Ilheus and lies in a landscape dominated by cabruca, in which secondary forest fragments and open areas (e.g. pastures) are embedded. 60 permanent study sites (plots) were established in a project area of approximately $10km^2$. The project area thereby includes 20 farms including those owned by AMAP (Fazenda Bom Pastor and Julia) and neighboring farms such as Fazenda Santa Rita and Fazenda Almada. In advance, neighboring farm owners, administrators and cooperative representatives of the fazendas were contacted and agreed to collaborate with a total of 28 stakeholders in the EAI project. After that, 60 plots were established, each with a size of $40m^2$.



The study area of the EAI-Project in Southern Bahia, Brazil (a). We selected a 10 km² area suitable to establish the EAI research plots (b). We established 60 research plots encompassing a gradient of habitat succession, (c). We splitted the plots into simple and complex landscape surroundings with five plot replicates per succession habitat and landscape surrounding.

The plots are divided into 6 habitat categories, each with 10 replicates:

1. old secondary forest (Old forest)
2. young secondary forest (Intermediate forest)
3. cabruca with native tree species (Native agroforest)
4. cabruca with non-native tree species (Non-native agroforest)
5. cabruca with few shade trees (Low shade cocoa)
6. Open areas

The 10 replicates per habitat category were additionally related to surrounding vegetation structure and diversity, and each was divided into 5 simple and 5 complex plots. The first three-year project phase is divided into four work programs (WP) corresponding to the project objectives:

I. Investigation of the spatio-temporal changes of tree species along a land use gradient over time.

II. study of spatio-temporal changes in pollination performance and pest infestation in the Cabruca.

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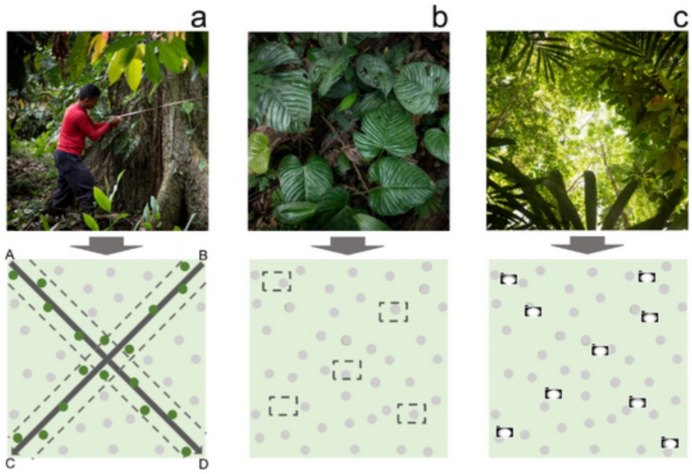
III. linking socio-ecological factors in a predictive model with spatio-temporal land use changes to understand boom and bust cycles of cacao

IV. Knowledge transfer: "best practice management" for biodiversity conservation and sustainable cocoa cultivation.

IV. Work Program (WP) of the EAI project

WP I - Land use change over time

The work in WP I has already started in May 2022. Monitoring is carried out by three research assistants. The training and plot selection was done by Dr. Manuel Toledo-Hernandez. An initial comprehensive vegetation characterization of trees and shrubs was conducted during the setup of the 60 study plots. This included recording the number of species, abundance, and age of the trees (determined by trunk diameter at breast height, DBH, and estimation of tree height). Therefore, two diagonal transects were walked to plot corners and all trees/shrubs with a DBH >20 cm were recorded and their abundance counted within a 1m distance to the right and left of the transect. All trees with a DBH >40cm within the plot were recorded to determine the diversity of mature trees. Ground vegetation and organic soil cover thickness were recorded on 5 randomly selected $1m^2$ plots within the plots. Finally, shading of the plot by the tree canopy was estimated using 9 plot photos. Images were processed using Image J software to quantify percent shading (Wanger et al., 2011). Vegetation characterization is conducted three times per year. The dataset resulting from vegetation monitoring is used to calculate the potential for carbon storage in different cabruca land uses. Furthermore, the dataset forms the basis for WP II biodiversity monitoring and is used to develop models on boom and bust cycles of cocoa production (WP III).



Schematic figure of tree plant monitoring for WP1. First, we monitor tree/shrub species composition (i.e. species diversity, abundance) using a walking transect approach (a). Then, we establish five $1m^2$ quadrates and record vegetation cover (i.e. percentage of vegetation, soil litter thickness in cm; b). Finally, we monitor tree shade canopy cover above 4 m height using nine canopy photos randomly take within the research plot (c).

WP II - Investigation of spatio-temporal changes in pollination performance and pest infestation in cabrucas.

WP II was started in October 2022. The implementation of the project is in the responsibility of a PhD student from UESC and the three AMAP research assistants. EcoEye cameras will be used to monitor the pollination of cacao flowers and subsequent fruit development. EcoEye cameras were developed at Westlake University's SASE Lab and use artificial intelligence-based software that can be trained to recognize different groups of animals. For the EAI project, the software was trained to detect cacao pollinators (insects), as well as birds and bats of the Cabrucas. Unlike conventional photo traps with infrared sensors, EcoEye cameras only trigger when a trained algorithm detects the desired image features. This allows monitoring of a wide range of animals, including tiny cacao pollinators, at lower cost and with greater efficiency and scalability.

For pollination monitoring, 6 cocoa trees of the same variety are selected for each of the 30 cabruca plots. Two flowers at different heights per tree will be selected on each cocoa tree. Thus, a total of 360 cocoa flowers on 30 cabruca plots will be examined for this study. Cameras will record pollinator diversity (including

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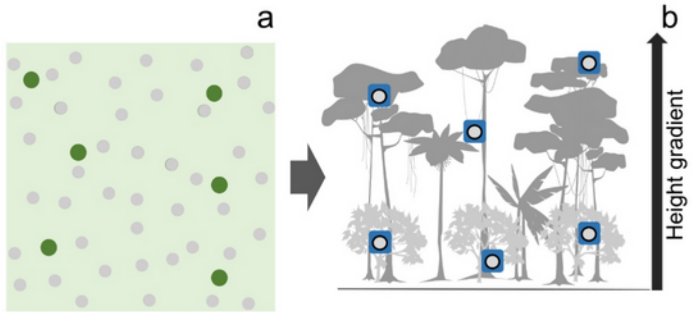
abundances and frequency and length of visit) at each flower for 24h. Recording will be conducted three times per flower. Overall monitoring will be repeated three times and conducted three times per year. For pollination monitoring, 6 cocoa trees of the same variety are selected for each of the 30 cabruca plots. Two flowers at different heights per tree will be selected on each cocoa tree.

Schematic overview of the experimental set-up for WP2 "pollinator monitoring" using EcoEye cameras. EcoEye cameras, developed by research team in Westlake University, China, using sophisticated machine learning tools to record with high accuracy ecological processes, such as pollination visitation, and pollination success (a). The EcoEye cameras will be deployed in the EAI research plots by a trained research team from UESC (b). We will first select six healthy cocoa trees of the same variety in each of the cocoa research plots. Then, we will establish two cameras in two separated flowers, each at two different tree heights (low = <1 m height, high = >3 m height), and monitor cocoa pollinator visitors, fruit set, and fruit development (c).

For bird and bat monitoring, 6 cameras will be placed per cabruca plot, resulting in a total of 180 randomly selected camera locations. The cameras will be distributed over two different heights (three cameras at low height = <3 m and three cameras at high height => 5 m) to obtain a height gradient and to capture the effects of cabruca vertical structure on pests, herbivores, and predators. To correlate flower pollination and pest infestation, fruit development will be recorded on all 6 sampled cocoa trees per plot. This involves marking and counting the total number of open flowers per tree. Then, 48 h after the flowers are marked, pollination success is recorded. Finally, fruit development (i.e., fruit wilt, pests and diseases, healthy fruit) of pollinated flowers is tracked each month until harvest, and yields (the dry weight of cocoa beans) are quantified.



Schematic overview of the experimental set-up for WP2 "bird and bat monitoring" using AI-based biodiversity monitoring cameras. We will deploy the cameras in six points randomly distributed across the research plot (a). Cameras will be established at two different height gradients (low = <3 m, and high = > 5 m height) with three camera replicates for each gradient, giving a total of six EcoEye cameras per plot (b)cameras will be deployed in the EAI research plots by a trained research team from UESC (b).

WP III - Linking socio-ecological factors in a predictive model with spatio-temporal land use changes to understand boom and bust cycles of cocoa.

WP III will first conduct semi-structured surveys of farmers participating in the EAI project to assess the general socio-economic situation and farming practices on the study plots. This will provide initial insight into the social and economic drivers of land use change within the EAI study areas. The survey will focus on demographic data (such as age, gender, schooling, household size), land use history (such as previous land uses), general agro-ecological knowledge (such as under-standing of cabrucas for ecosystem service provision), and farm management (such as inputs, farm yields). In a second step, a survey will be conducted among cacao stakeholders (i.e., smallholders, administrators, landowners, association representatives) in the municipality of Uruçuca (where the EAI Project area is located) to identify regional socioeconomic structures, farming practices, and major difficulties in developing sustainable cacao production. In both cases, at the local level (with stakeholders involved in the EAI Project) and at the regional level (stakeholders in the municipality of Uruçuca), surveys will be conducted three times per year, with four months between each survey. Results from WP I and II will be integrated into a Bayesian

Structural Equation Model (SEM) to examine how land use changes over time alter agricultural yields and ecosystem service provision. Data from WP I-III will be linked to high-resolution landscape features and extrapolated to Brazil via modeling. Modeling of the datasets will be conducted by a second UESC student, as part of a PhD thesis.

WP IV - Knowledge Transfer - "best practice management" for biodiversity conservation and sustainable cocoa cultivation

In WP IV, knowledge communication will take place. Three times a year there will be a report on the current status of the projects. This will be written by the coordinator of the EAI project Dr. Manuel Toledo-Hernández, the PhD students involved in the work areas and AMAP. Twice a year, a meeting is held with the stakeholders involved in the EAI project (farm owners, administrators, community representatives) to exchange and discuss project-related problems. At the end of the three years of the project, a workshop will be held to which all interested stakeholders will be invited and where the final results and the main recommendations on agro-ecological practices, for sustainable cocoa production, etc. will be presented. Finally, a book summarizing our major results, and outcomes will be publicly available as PDF, and hard copies stored at the UESC for the university community to access freely.

V. Project team

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Project coordinator

Dr. Manuel Toledo-Hernández
PostDoc in the Sustainable Agricultural Systems & Engineering Laboratory, School of Engineering, WU, China;, Coordinator of the Global Agroforestry Network.
Dr. Toledo-Hernandez is the project coordinator, and his research focuses on the ecological and socioeconomic interrelationships of agro-forestry systems such as cacao and coffee. During his PhD at the University of Göttingen, he focused on cacao agroforestry systems in Indonesia. He already conducted a hand pollination project of cocoa trees in cooperation with AMAP in 2019, during a research stay at Fazenda Bom Pastor.

Local coordinator

Dr. Joanison Vicente dos Santos Teixeira
Project Coordinator AMAP Brazil; Post Doc at the UESC in the Laboratório de Etno-conservação e Áreas Protegidas (LECAP).
Dr. Teixeira is hired by AMAP as project coordinator. Within the EAI Project he coordinates the local project teams and the networking with partners

Technical assistants

Msc. Julian Barillaro, UESC

Julian Barillaro received his master's degree from UESC and was hired by UESC as a technical assistant for the EAI project. He coordinates the monitoring of pollination and fruit development of cocoa flowers along a land use gradient (WP II). He is also responsible for programming and maintaining the EcoEye cameras.

Msc. Valentina Fortunato, UESC.

Valentina Fortunato received her master's degree from UESC and was hired by UESC as a technical assistant for the EAI project. She coordinates the monitoring of socio-ecological factors of land use change and conducts the surveys (WP III).

PhD students

Leonardo Marques de Abreu has a scholarship from UESC and is doing his PhD on the amphibian community in the EAI-Project area.

Research Assistants

Alisson Calasans Lima, AMAP.
Erasmo Alves Demetrio, AMAP.
Deivson dos Santos Brandao, AMAP.

Three research assistants are provided by AMAP to carry out the basic monitoring on the 60 research plots. They are responsible for plot maintenance and carry out fieldwork of the EAI-Subprojects under supervision. They are hired with a full time position.

Almada Mata Atlântica Projekt (AMAP)
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CNPJ: nº 29.014.200/0001-8
Ilhéus, BA, Brazil

Project Partner

Sustainable Agricultural Systems & Engineering Lab

Westlake University 西湖大学

Universidade Estadual de Santa Cruz - UESC

Stiftung Zukunft Jetzt!

Global Cocoa Pollination

Umweltstiftung Greenpeace

Global Agroforestry Network

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