Reforestation in Costa Rica Incentivized by the Payment for Environmental Services Program

A case study into the effectiveness of the PES program

Emilie Girard

Spencer Martel

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Introduction and Objectives

Costa Rica's ecosystems hold around 5% of the world's biodiversity, making the country one of the most important and diverse environments for sustaining plant and wildlife species today (Johnston, 2022). This vast biodiversity has encouraged the country to adopt policies and initiatives involving wildlife protection, conservation, and reforestation. As the planet's environmental state continues to decline, countries are rapidly turning towards models internationally to adopt their own measures deemed necessary for slowing climate degradation. Costa Rica is one country that is often used as an example for adopting environmental protection policies, considering it was named Champion of the Earth by the United Nations in 2019 (Andrews, 2014).

Costa Rica excels particularly well in the field of reforestation since the implementation of national environmental protection policies such as the Payment for Environmental Services program (PES) in 1996. A report by Tafoya et al., (2020) suggests that Costa Rica successfully reversed deforestation by restoring forest cover from 24.4% in 1985 to >50% by 2011. This statistic implies the success of the country's unique model consisting of local participation in forest protection, reforestation, sustainable forest management and agroforestry (Tafoya et al., 2020). However, little research has been done on change detection in specific areas throughout the country relating to the PES programs.

Focusing on the region near the municipality of Cabo Blanco and the Central Pacific Conservation Area, this project analyzes reforestation patterns relating to the implementation of PES programs in Costa Rica from 1985-2022. The study uses satellite imagery to detect vegetation cover prior to the introduction of the programs (1960-1996) and following its implementation (1996-present) as an indicator for the program's success.

A. *Project Objectives*
   i. Produce visualizations using Landsat imagery on land cover changes in the Cabo Blanco Region and the Central Pacific Conservation Area pre and post 1996.
   ii. Analyze the success of the PES programs in Costa Rica by comparing a pre-existing map of programs and our final maps indicating change detection.

B. *Research Questions*
   i. Has the amount of vegetation in the Cabo Blanco Region and the Central Pacific Conservation Area changed significantly since 1996, and how so?
   ii. Are the results of the research an indication of the success of the implementation of the PES programs in the country?

Literature Review

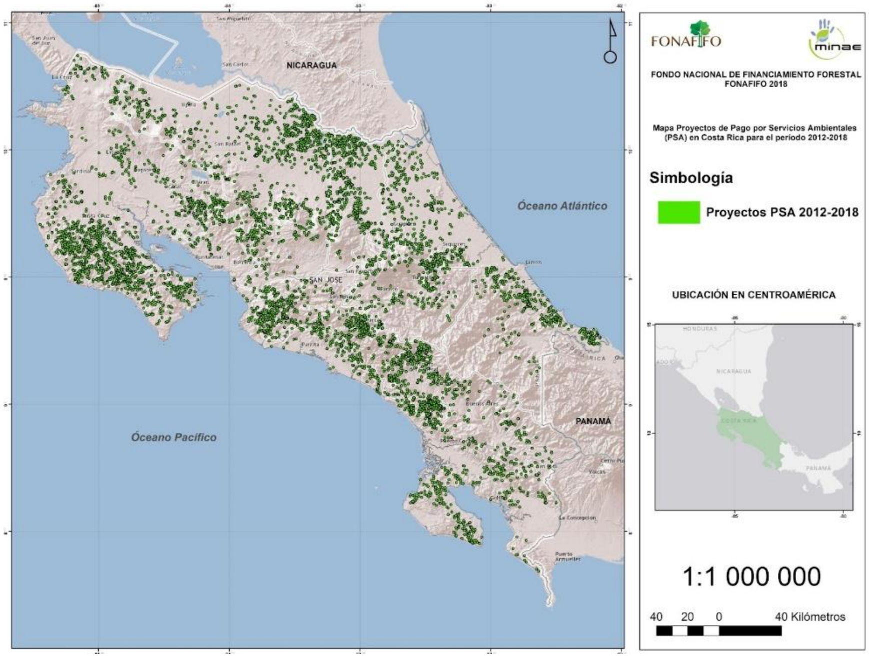
Beginning in the 1960s, Costa Rica saw a significant increase in deforestation rates, resulting in forest cover representing only 25% of the national territory. In 1996, the country implemented a government-led Payments for Environmental Services program (PES) in response to the decline in forest cover. This program was created in conjunction with the Forestry Law 7575 of 1996, "which recognizes four environmental services: (1) mitigation of greenhouse gas emissions, (2) water protection, (3) protection of biodiversity, and (4) provision of scenic beauty" (Arriaga et al., 2012, p.3). Furthermore, the PES program works with landowners for five-year contracts whereby direct payments are made to owners who engage in forest protection, reforestation, sustainable forest management and agroforestry (Porras et al., 2018). Statistics show that the rate of deforestation has vastly declined since the implementation of these services, and forest cover was restored to 51% by 2005 (CPI, 2022).

A previous study by Arriagada et al. (2012) used remote sensing and statistical data to determine the success of reforestation through the PES programs in Sarapiqui, Heredia. The research used aerial photographs to analyze deforestation rates at a farm-based level. However, Landsat 5 satellite images were used in some instances where aerial photographs from previous years were missing or included too much cloud-cover (Arriagada et al., 2012). Results found that the PES programs had a moderate impact on forest cover, with about a 10% to 15% increase in forestation since the implementation of the programs (Arriagada et al., 2012). The authors argue that more empirical studies are necessary to properly assess the success of PES programs in Costa Rica outside Sarapiqui's region. Since our research covers larger regions, we will use Landsat satellite images to measure the success of reforestation in the Cabo Blanco Region and the Central Pacific Conservation Area.

Methodology

Our methodology for analyzing reforestation efforts in Costa Rica pre and post PES implementation began with looking for suitable study areas. Since the PES program was implemented in 1996, we needed photographs from pre 1996 to use as a baseline. We selected Landsat imagery as our source based on the historic data availability, its (very) cost effective price, and the 30m resolution of its Thematic Mapper sensor were satisfactory in finding land use changes. We wanted to find areas where we knew PES funding had gone and came across the map shown in figure 1.

Figure 1.

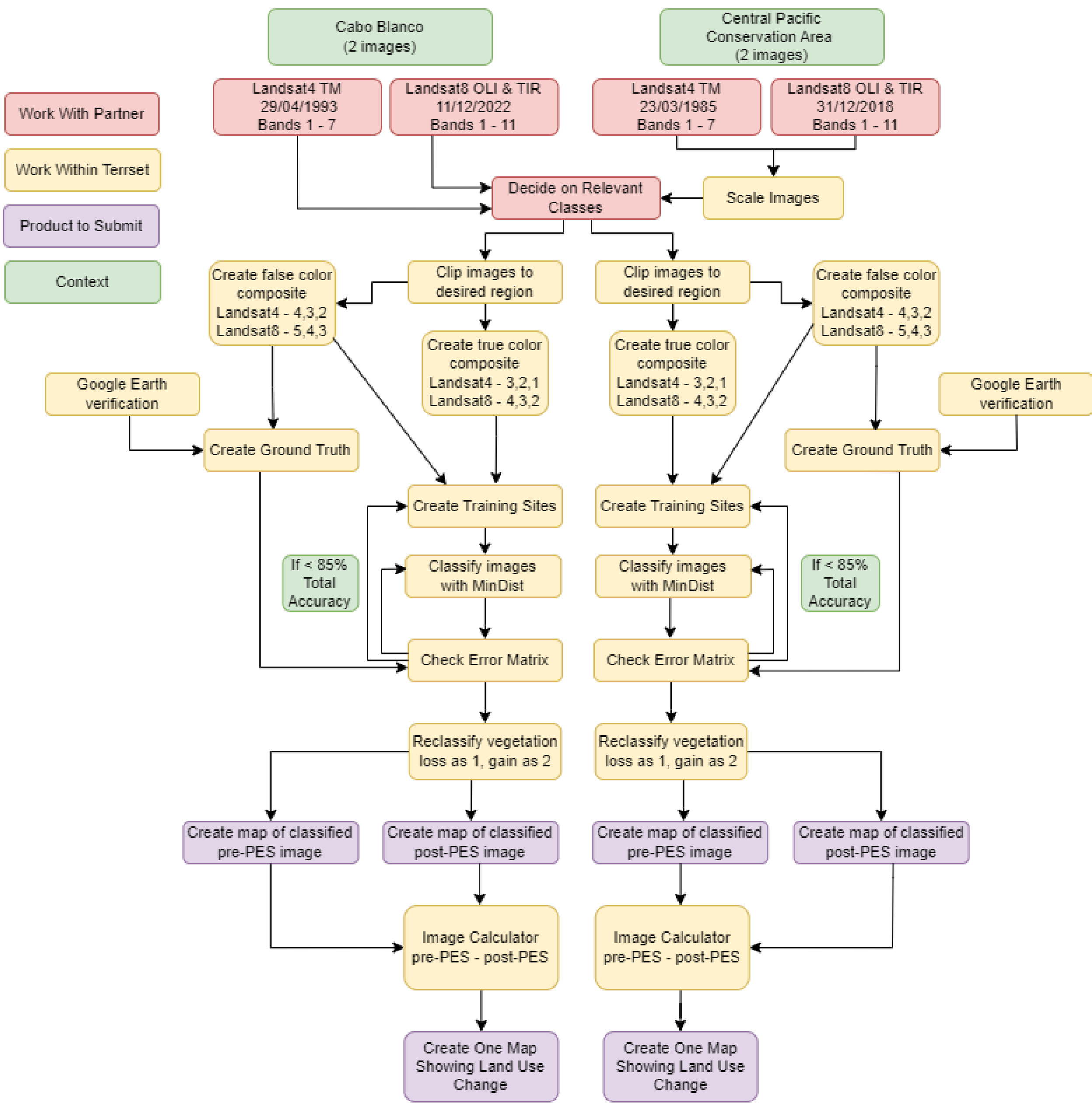


Note: Map of Payment for Environmental Services (PES) Projects in Costa Rica for the period 2012-2018. Courtesy of the Convention for Biological Diversity of Costa Rica.

After searching for Landsat imagery, we decided on the Cabo Blanco region in the West and the Central Pacific Conservation area in Puntarenas. Since this was a study focusing on vegetation, we needed to have pictures from roughly the same time of year. We decided that photos taken from the rainy season would be best for our study since vegetation is likely to be healthier.

Having decided on our locations we began a discussion on how many and which classes we would like to include in our final maps. After delving into the literature surrounding Costa Rica's PES program, we found that one of the main initiatives was to offer farmers a cost-effective alternative to cattle farming (*Reforesting Costa Rica through Payments for Environmental Services*). This was the driving piece in deciding which land use classes to look for. Since we wanted to see if farmers had properly been incentivized towards greener land uses, we decided classifying water, soil, and vegetation would be sufficient in seeing whether the program was having an effect. We initially wanted to include urban so as to not lump it into one of the other classifications. This caused issues in the classifications as none of the algorithms were good at discerning the small amount of urban land use we had in our images. With our data found and our classifications set, we went about processing the images and followed the workflow found in figure 2, our flowchart.

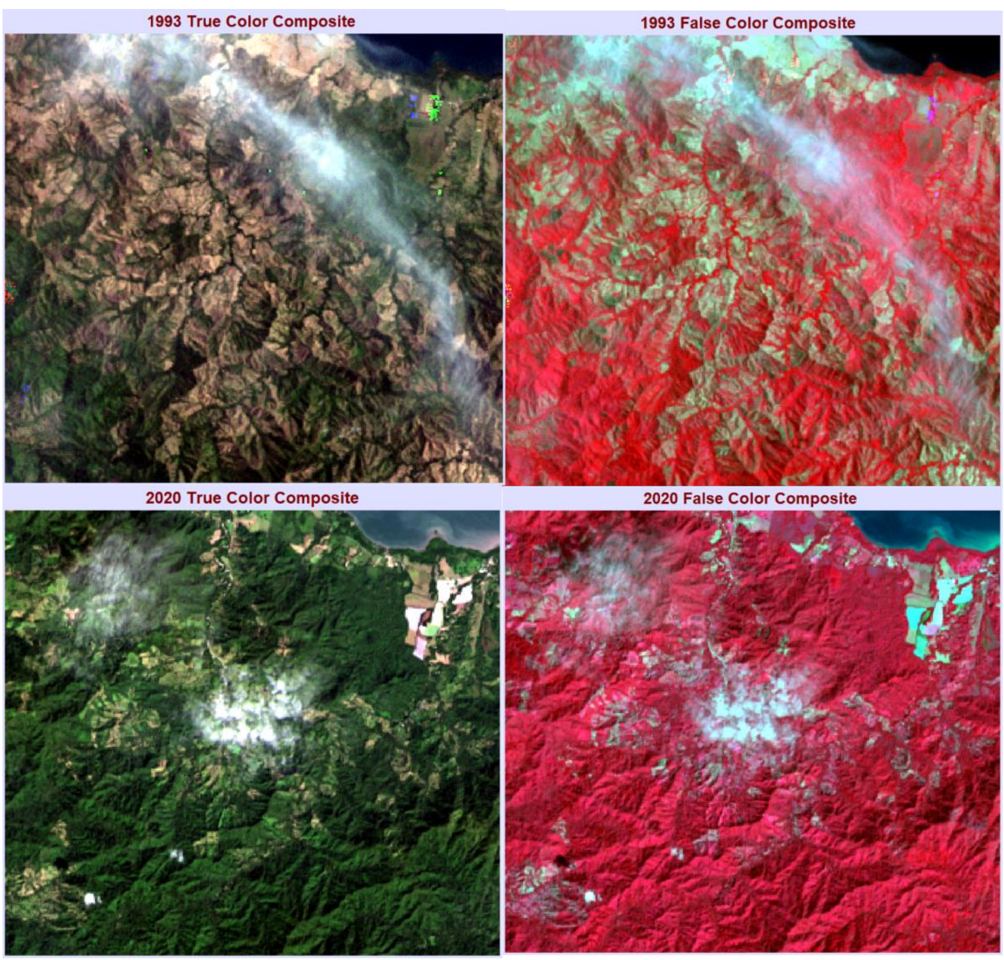
Figure 2.



Note: Flowchart

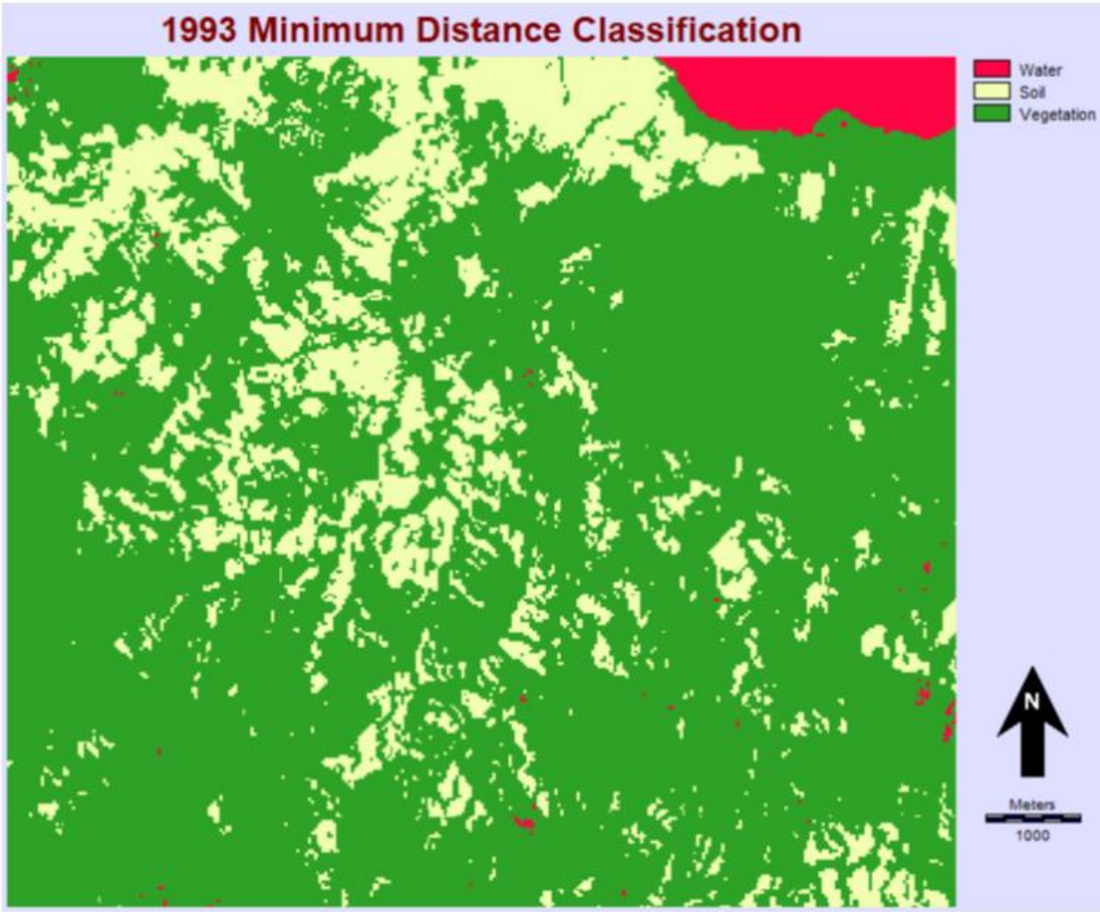
Once true and false color compositions were made, we felt confident that our analysis would yield the expected results of a shift in land use from soil to vegetation as shown in figures 3 and 4. A key decision was made regarding which classification method to use. It seemed sounder to have a singular classification method be used for all 4 of our images to come to more reputable comparative conclusions. For this, we found the supervised minimum distance classification method to do the best job of representing reality and fit our ground truth analyses quite well. Figure # shows the results of the classification methods for both years, for both regions and their associated error matrices.

Figure 3.



Note: True and false color compositions of the Cabo Blanco region depicting the change in land use from soil to vegetation.

Figure 4.



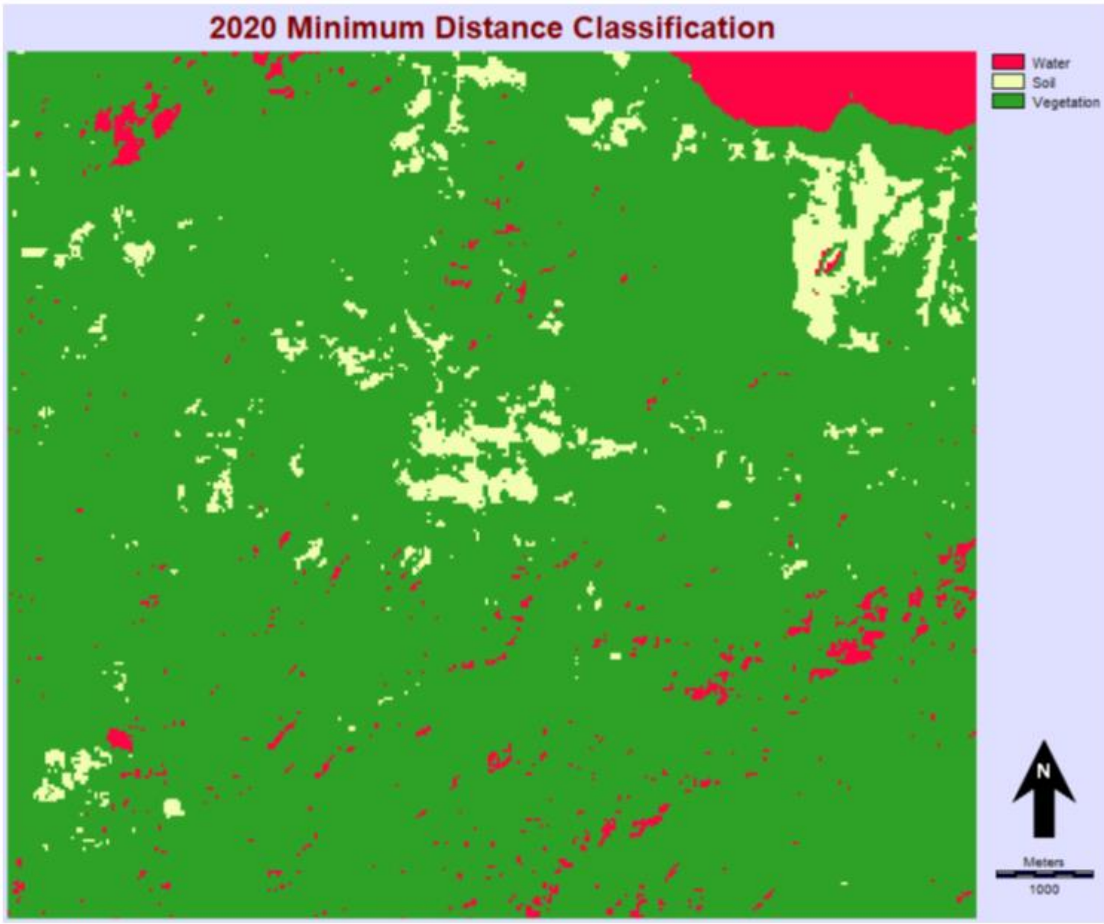
	1	2	3	Total	ErrorC
1	288	0	1	**289**	**0.003460**
2	0	297	0	**297**	**0**
3	0	0	405	**405**	**0**
Total	**288**	**297**	**406**	**991**	
Error0	**0**	**0**	**0.002463**		**0.001009**

Note. Cabo Blanco 2020 classification map using the minimum distance classification method and associated error matrix

Total accuracy

((288 + 297 + 406) / 991) * 100 = **99.9%**

Figure 5.



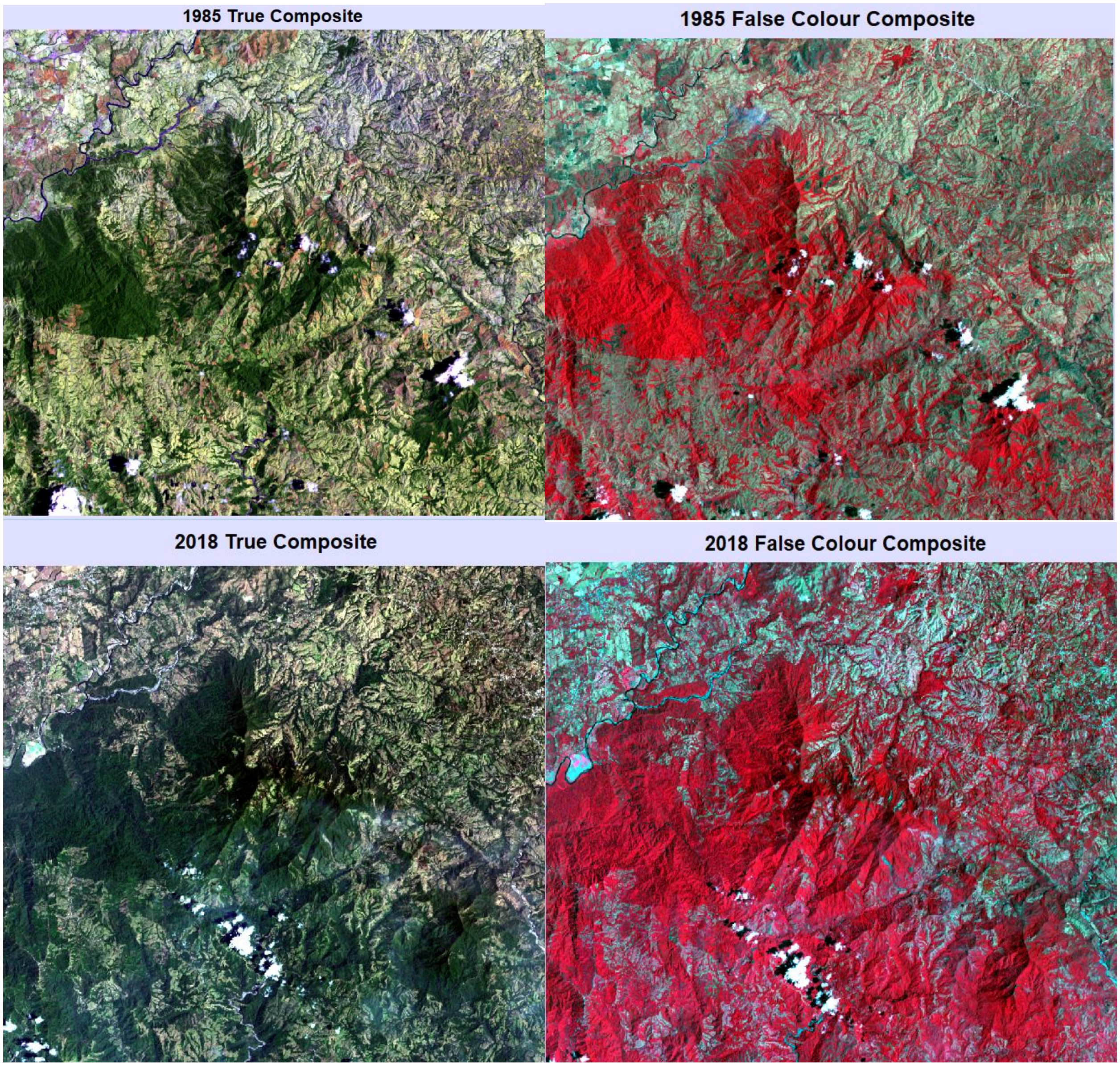
	1	2	3	Total	ErrorC
1	246	3	2	251	0.019920
2	0	131	0	131	0
3	0	0	1115	1115	0
Total	246	134	1117	1497	
Error0	0	0.022388	0.001791		0.003340

Note. Cabo Blanco 2020 classification map using the minimum distance classification method & associated error matrix.

Total Accuracy:

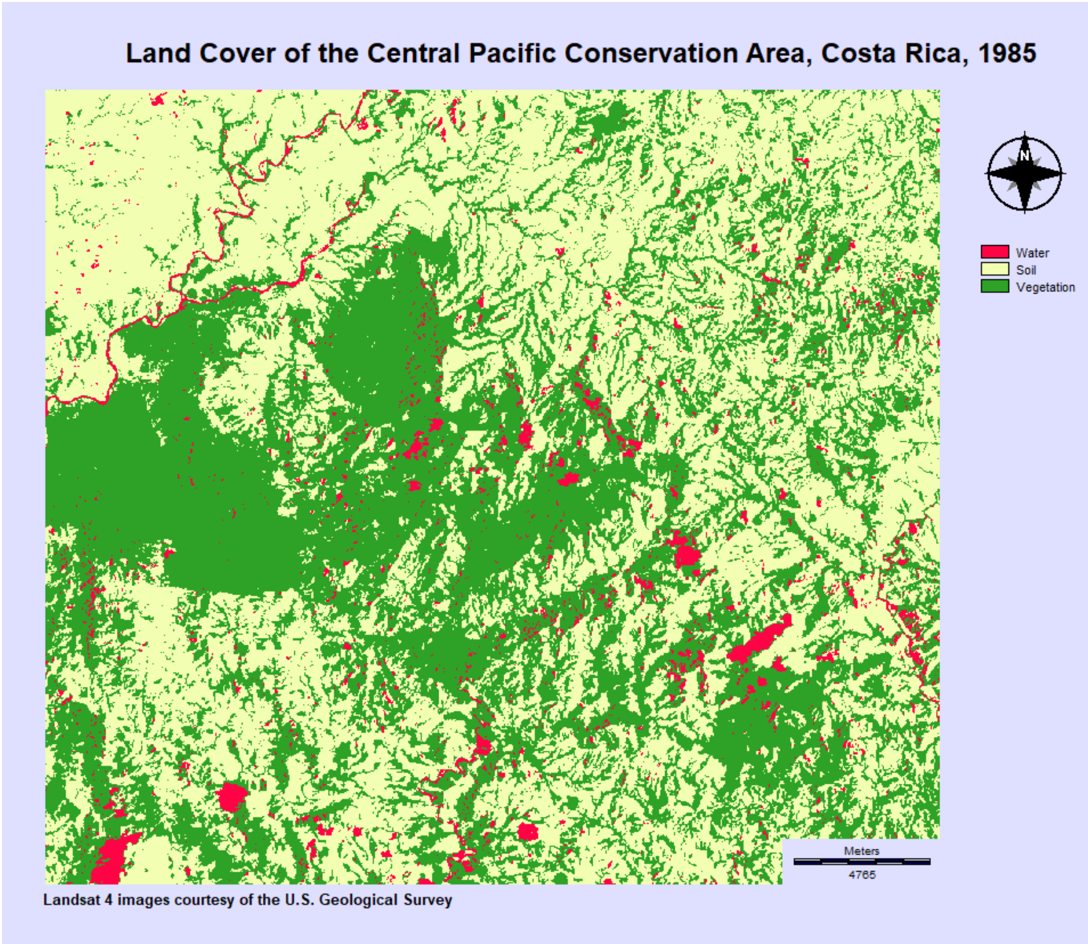
((246 + 131 + 1115) / 1497) * 100 = **99.7%**

Figure 6.



Note: True and false color compositions of the Central Pacific Conservation Area depicting the change in land use from soil and vegetation

Figure 7.



Error Matrix Analysis of MINDIST1985_GT (columns : truth) against MINDIST1985 (rows : mapped)

	1	2	3	Total	ErrorC
1	29562	674	1222	31458	0.060271
2	0	496183	0	496183	0
3	51	14590	398338	412979	0.035452
Total	29613	511447	399560	940620	
ErrorO	0.001722	0.029845	0.003058		0.017581

ErrorO = Errors of Omission (expressed as proportions)
ErrorC = Errors of Commission (expressed as proportions)

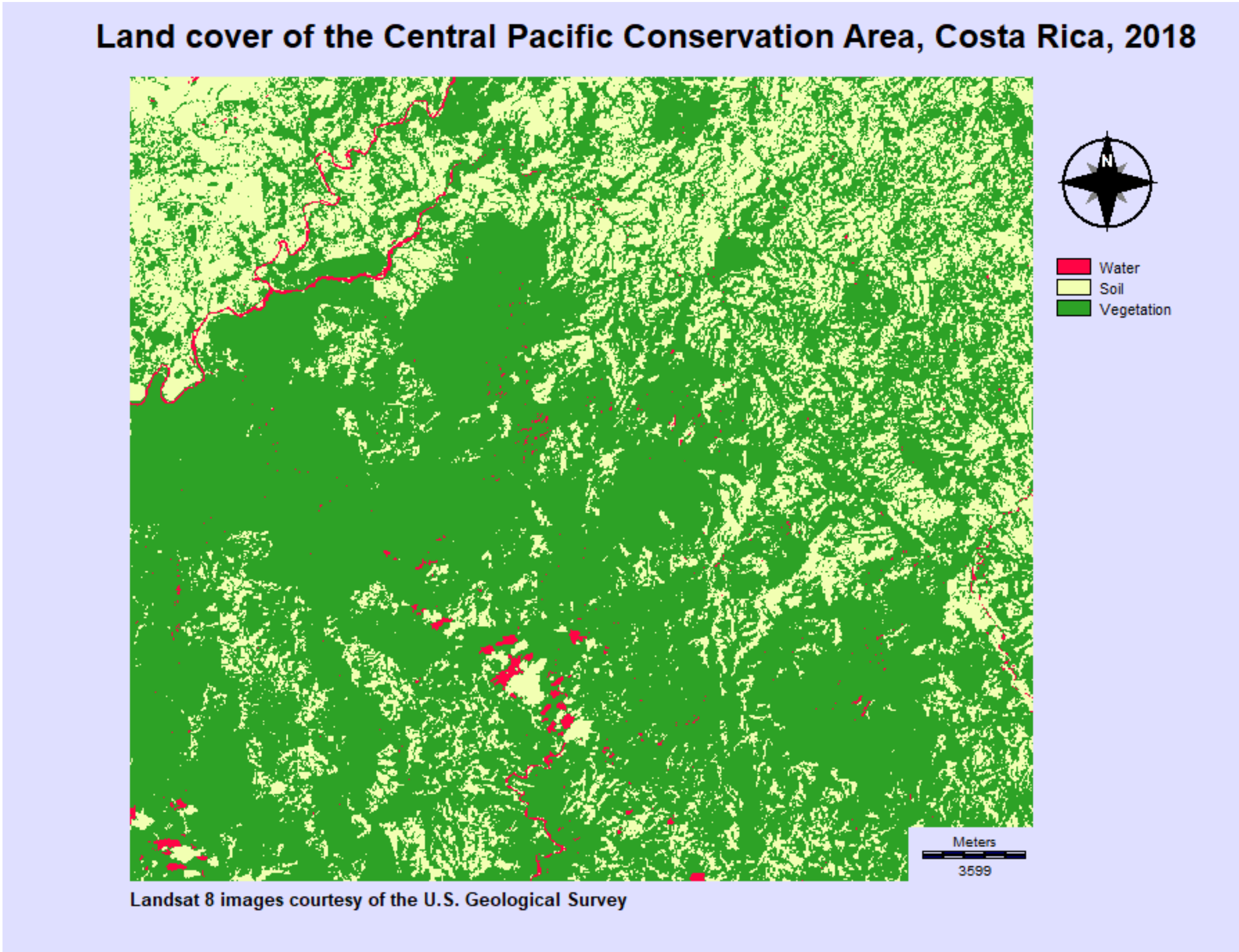
90% Confidence Interval = +/- 0.000223 (0.017358 - 0.017804)
95% Confidence Interval = +/- 0.000266 (0.017315 - 0.017847)
99% Confidence Interval = +/- 0.000350 (0.017231 - 0.017931)

Note: Central Pacific Conservation Area 1985 classification map using the minimum distance classification method & associated error matrix.

Total Accuracy:

((8936 + 246901 + 675952) / 940620) * 100 = **99%**

Figure 8.



Error Matrix Analysis of MINDIST1985_GT (columns : truth) against MINDIST1985 (rows : mapped)

	1	2	3	Total	ErrorC
1	29562	674	1222	31458	0.060271
2	0	496183	0	496183	0
3	51	14590	398338	412979	0.035452
Total	29613	511447	399560	940620	
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95% Confidence Interval = +/- 0.000266 (0.017315 - 0.017847)
99% Confidence Interval = +/- 0.000350 (0.017231 - 0.017931)

Note: Central Pacific Conservation Area 2018 classification map using the minimum distance classification method & associated error matrix.

Total Accuracy:

((29562 + 496183 + 39338) / 940620) * 100 = **98.2%**

Once we had completed the classification maps for each image, we used the IMAGE CALCULATOR tool in Terrset to subtract the post-1996 images from the pre-1996 images. This produced our finalized maps showing vegetation gain and vegetation loss. The final data was transferred to ArcGIS Pro where mapping properties such as legends, titles, and scale bars were added. We also retrieved the area of each land use for the four classified images to obtain overall areas (in hectares) of vegetation cover, which are demonstrated in the calculations section below.

Calculations

Group 1 - Capo Blanco Region

Area on file: 1993_MinDistRaw

Category	Hectares	Legend
1	226.350000	Water
2	1799.190000	Soil
3	7019.460000	Vegetation

Area on file: 2020_MinDistRaw

Category	Hectares	Legend
1	387.360000	Water
2	437.850000	Soil
3	8219.790000	Vegetation

Area of vegetation in 1985: 7019.46 hectares

Area of vegetation in 2018: 8219.79 hectares

Calculation: 8219.79 – 7019.46 = 1200.33 hectares

Group 2 - Central Pacific Conservation Area

Area on file: MinDist1985

Category	Hectares	Legend
1	2831.220000	Water
2	44656.470000	Soil
3	37168.110000	Vegetation

Area on file: MinDist2018

Category	Hectares	Legend
1	805.140000	Water
2	22712.400000	Soil
3	61138.260000	Vegetation

Area of vegetation in 1985: 37168.11 hectares

Area of vegetation in 2018: 61138.26 hectares

Calculation: 61138.26 - 37168.11 = 23,970.15

Final Results

Region	Increase in Vegetation (ha)
Capo Blanco	1, 200.33 ha
Central Pacific Conservation Area	23, 970.15 ha

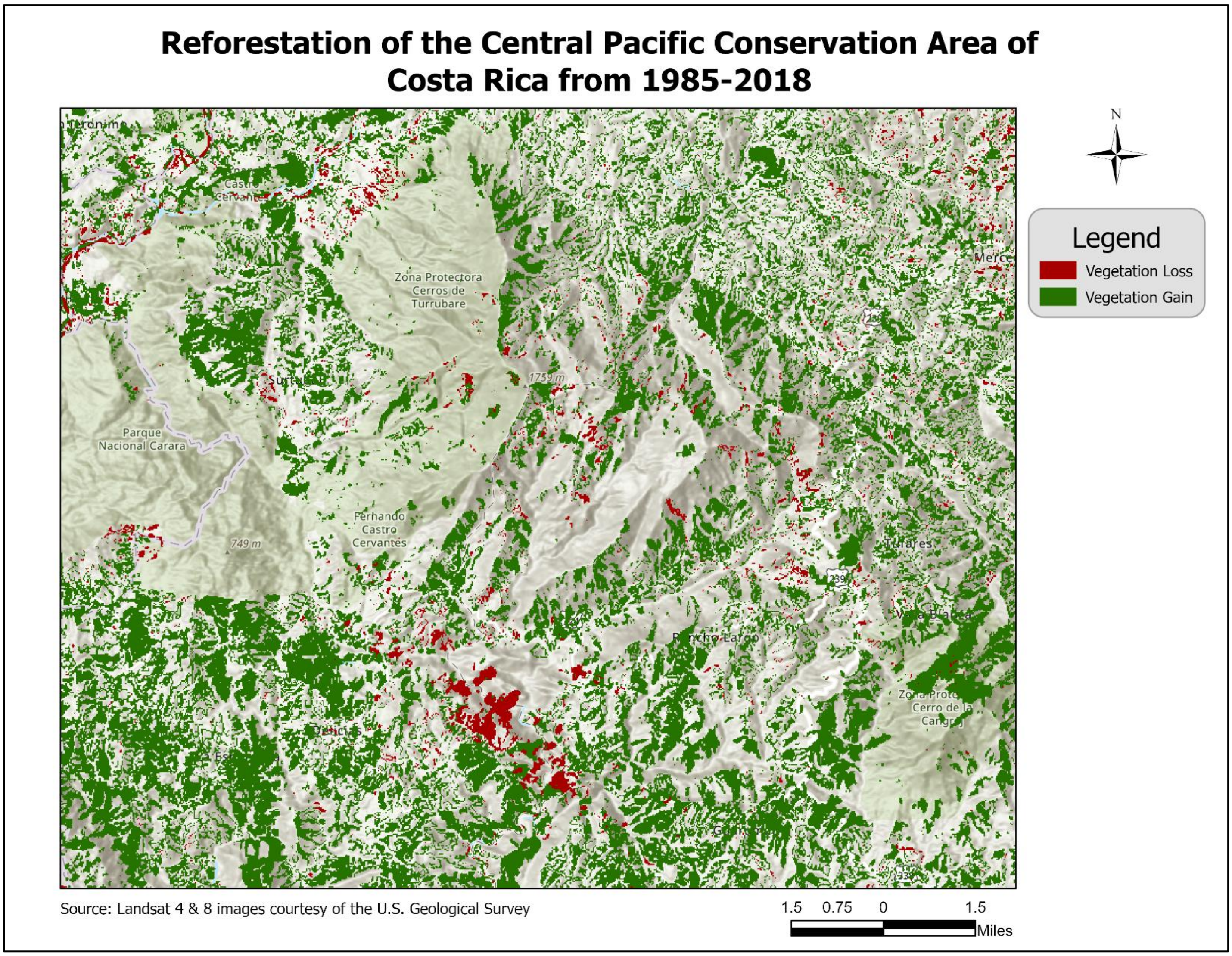
Results

The final maps of this project indicate a significant change in vegetation cover in the Cabo Blanco region and the Central Pacific Conservation Area. We observed an increase in vegetation for both regions just by observation throughout the initial mapping process using the classification methods for all images. Furthermore, the positive change in vegetation cover became increasingly apparent with our final maps and with the calculations of area change for each image pre-1996 and post-1996.

The Central Pacific Conservation Area had an increase in vegetation cover of 23,970 ha or 64% from 1985 to 2018. Notably, masking was not used to hide cloud coverage but the area of clouds was measured using the TerrSet measuring tool. For the Central Pacific Conservation

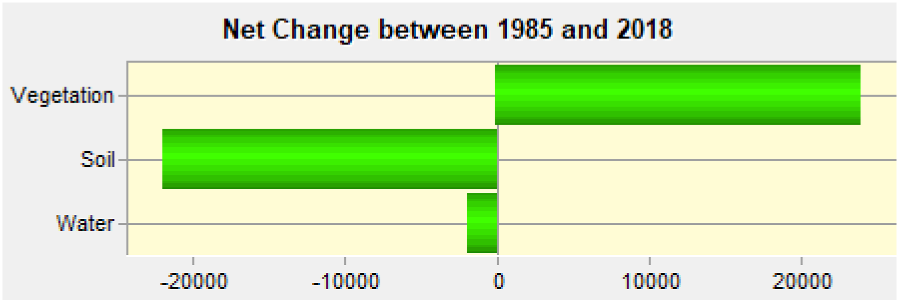
Area, the cloud area resulted in 1.7 hectares. Large portions of the study area remained unchanged due to the existing national parks such as the Carara National Park and La Cangreja National Park. Nonetheless, surrounding areas of the national parks that were affected by deforestation and agriculture in 1985 significantly changed to vegetation by 2018. When comparing the final map to PES programs (Figure 1), our findings suggest that the presence of PES funding in the area positively impacted vegetation cover.

Figure 9.



Note. Map indicating vegetation loss and vegetation gain in the Central Pacific Conservation Area of Costa Rica from 1985-2018.

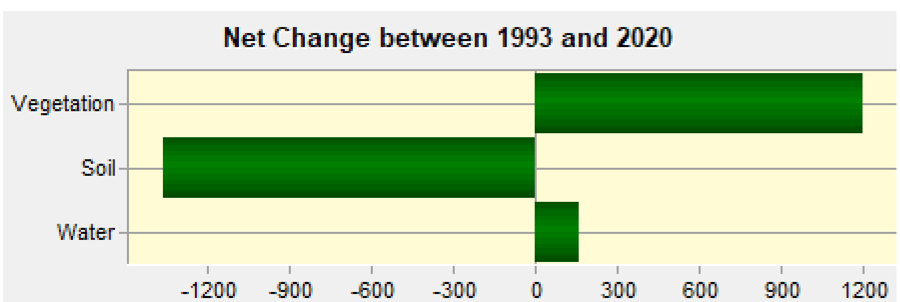
Figure 10.



Note. Map indicating net change of vegetation, soil, and water in the Central Pacific Conservation Area of Costa Rica from 1985-2018.

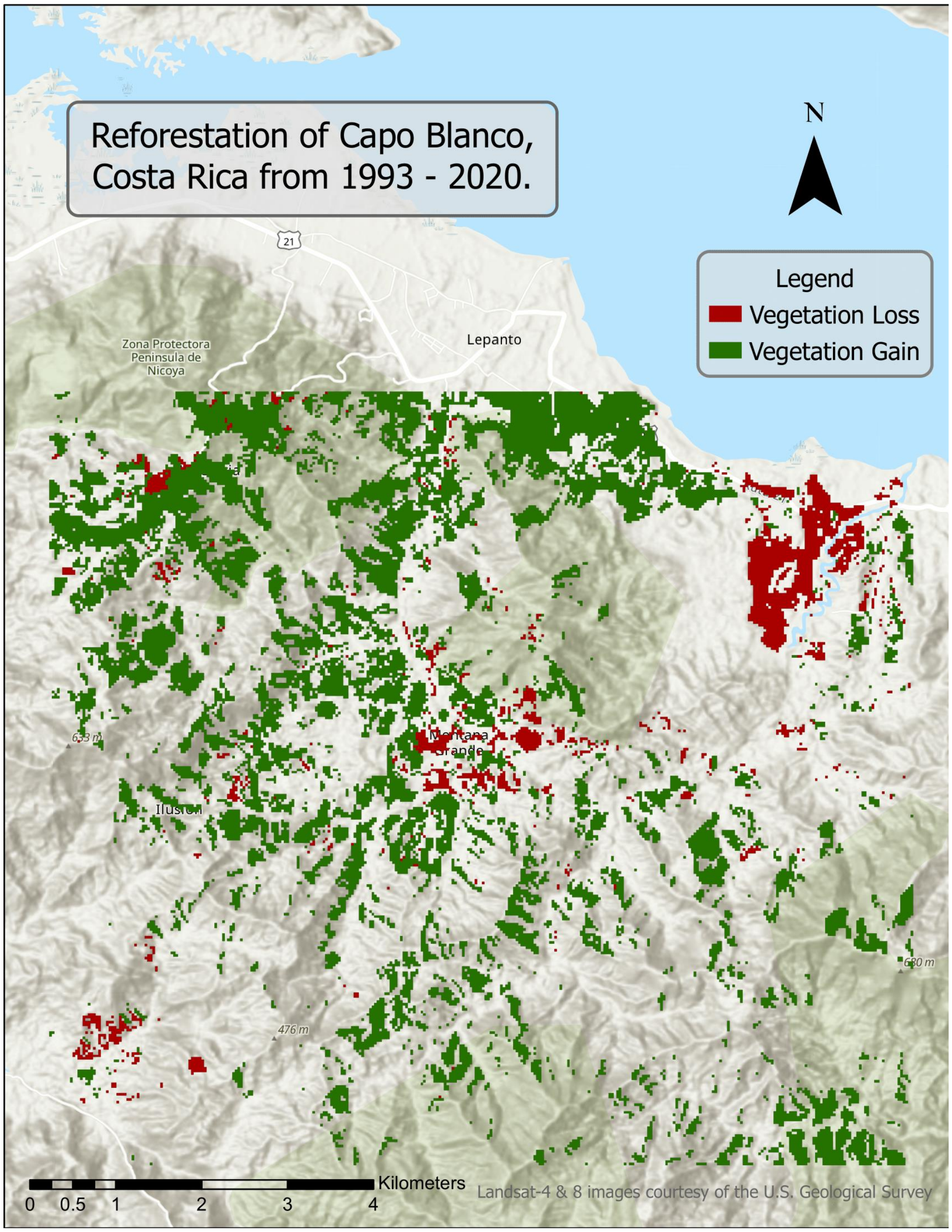
The region near the municipality of Cabo Blanco additionally experienced significant increase in vegetation cover from 1993 to 2020 (insert numbers here). The amount of cloud coverage calculated using the TerrSet measuring tool resulted in 1.8 hectares. The area that experienced the most vegetation loss was in the north-west region of Cabo Blanco to agricultural farming. However, other sites substantially increased in vegetation and can be compared to figure #. demonstrating the implementation of payments for ecosystem services. This suggests that there is an impact on vegetation cover related to the engagement in reforestation practices provided through the PES program.

Figure 11.



Note: Map indicating net change of vegetation, soil, and water in the Cabo Blanco region of Costa Rica from 1993-2020.

Figure 12.



Note. Map indicating vegetation loss and vegetation gain in the Cabo Blanco from 1993-2020.

Discussion

Following the study by Arriagada et al. (2012), we selected areas of study that have active PES programs to identify vegetation change in our own areas. Our findings demonstrate that the regions surrounding Cabo Blanco and the Central Pacific Conservation area have had an increase in overall vegetation since 1993 and 1985, respectively. Although we did not overlay the data from the map of Payment for Environmental Services (Figure 1) onto our final maps, we have compared the maps to propose a correlation between the implementation of PES programs and the increase in vegetation. Our study suggests a correlation is possible, although a definitive statement cannot be made due to the limitations and time constraints of this research project.

Future research would need to specify the exact correlation between the implementation of PES programs and reforestation efforts in these areas to truly determine their relationship. This could be done by adopting measures from research that has studied the effects of PES programs in other parts of Costa Rica. For example, the study conducted by Azofeifa et al. (2007) used a combination of remote sensing data, GIS databases, and econometrics to establish the effects of forest cover in each PES area of the country. A secondary option would follow Arriagada et al.'s model of "establishing the difference between the expected potential change in forest cover on PES farms with PES contracts and the counterfactual expected potential change in forest cover on PES farms without PES contracts" (2012, p. 6). The methods from these studies could be applied in conjunction with the methods we have conducted in this project to provide a thorough analysis of reforestation on a small and broad scale.

Some limitations were faced during our study. We struggled with creating proper ground truths and one large discussion of ours centered around the proper methodology for remote assessment of the ground truth of a location. If it is us providing the training sites and the ground truth, both created in a similar manner, we are bound to end up with highly "accurate" classifications. If this were a more thorough study, we would have grabbed several pre and post-PES images to establish a trend of de and then reforestation. One of the main constraints for this project was the image processing methods that could be performed within a minor time frame given to conduct the research. In particular, we did not use masking tools for minimum amounts of cloud coverage, although ideally this would be performed when conducting an extensive research project as to not misclassify land use and the calculation of each area. For the project, we used the measuring tool to roughly calculate the identified clouds within our final maps.

Nonetheless, the incentivization and mobilization towards adopting practices engaging with reforestation and forest conservation align with the Forestry Law 7575 of 1996. In this sense, the PES programs should be understood as "a transfer of resources between social actors, which aims to create incentives to align individual and/or collective land use decisions with the social interest in the management of natural resources" (Farley et al., 2010, p. 4). The functioning of the PES programs makes part of an overall movement towards restoring forestry and adopting protection policies in Costa Rica. Therefore, we can interpret the increase in the vegetation of our study areas as being attributed to the conservation movement that began in 1996.

Conclusions

According to our results, it seems as though Costa Rica's Payment for Ecosystem Services program has been a great success. With gains of 1,200 hectares and nearly 24,000 hectares in the Capo Blanco and Central Pacific Conservation Area regions respectively, our findings back up the claims in the literature that Costa Rica's program has become a model for a market-based solution to changing land-use (Fletcher, 2020). We were ecstatic to see our findings were in line with those of other academics and we can conclude that it seems the PES program is properly incentivizing farmers towards greener use of their land.

References

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Metadata

This document was originally created as context to maps created for a study of reforestation in Costa Rica in 2 regions done by Emilie Girard and Spencer Martel.

Metadata Element Type	Definition
Title of the resource	1993 Minimum Distance Classification
Publication Information	Spencer Martel
Abstract	A classified map made in Terrset using the Minimum Distance classification method for the Cabo Blanco region in 1993.
Purpose	Originally developed as a resource to accompany a study on the PES program's effectiveness in 2 study areas in Costa Rica.
Spatial Extent	WRS Path: 16 WRS Row: 53
Temporal Extent	April 29th, 1993
Lineage	Landsat 4 Imagery, Terrset software (See flowchart for process)
Coordinate Reference System	WGS84

Metadata Element Type	Definition
Title of the resource	2020 Minimum Distance Classification
Publication Information	Spencer Martel
Abstract	A classified map made in Terrset using the Minimum Distance classification method for the Cabo Blanco region in 2018.
Purpose	Originally developed as a resource to accompany a study on the PES program's effectiveness in 2 study areas in Costa Rica.
Spatial Extent	WRS Path: 16 WRS Row: 53
Temporal Extent	November 11th, 2020
Lineage	Landsat 8 imagery, Terrset software (See flowchart for process)
Coordinate Reference System	WGS84

Metadata Element Type	Definition
Title of the resource	Reforestation of Cabo Blanco, Costa Rica from 1993 – 2020.
Publication Information	Spencer Martel
Abstract	A change map made in Terrset using the Image calculator function to show the change in land-use for the Cabo Blanco region from 1993 – 2020.
Purpose	Originally developed as a resource to accompany a study on the PES program's effectiveness in 2 study areas in Costa Rica.
Spatial Extent	WRS Path: 16 WRS Row: 53
Temporal Extent	April 29th, 1993 & November 11th, 2020
Lineage	Landsat 4 & 8 imagery, Terrset software (See flowchart for process)
Coordinate Reference System	WGS84

Metadata Element Type	Definition
Title of the resource	Land Cover of the Central Pacific Conservation Area, Costa Rica, 1985.
Publication Information	Emilie Girard
Abstract	A classified map made in Terrset using the Minimum Distance classification method for the the Central Pacific Conservation Area region in 1985.
Purpose	Originally developed as a resource to accompany a study on the PES program's effectiveness in 2 study areas in Costa Rica.
Spatial Extent	WRS Path: 15 WRS Row: 53
Temporal Extent	
Lineage	Landsat 4 imagery, Terrset software (See flowchart for process)
Coordinate Reference System	WGS84

Metadata Element Type	Definition
Title of the resource	Land Cover of the Central Pacific Conservation Area, Costa Rica, 2018.
Publication Information	Emilie Girard
Abstract	A classified map made in Terrset using the Minimum Distance classification method for the Central Pacific Conservation Area region in 2018.
Purpose	Originally developed as a resource to accompany a study on the PES program's effectiveness in 2 study areas in Costa Rica.
Spatial Extent	WRS Path: 15 WRS Row: 53
Temporal Extent	
Lineage	Landsat 8 imagery, Terrset software (See flowchart for process)
Coordinate Reference System	WGS84

Metadata Element Type	Definition
Title of the resource	Reforestation of the Central Pacific Conservation Area of Costa Rica from 1985-2018.
Publication Information	Emilie Girard
Abstract	A classified map made in Terrset using the Minimum Distance classification method for the Cabo Blanco region in 2018.
Purpose	Originally developed as a resource to accompany a study on the PES program’s effectiveness in 2 study areas in Costa Rica.
Spatial Extent	WRS Path: 15 WRS Row: 53
Temporal Extent	
Lineage	Landsat 4 & 8 imagery, Terrset software (See flowchart for process)
Coordinate Reference System	WGS84