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Comparison of land use change in payments for environmental services and National Biological Corridor Programs

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ABSTRACT

Costa Rica established the National Biological Corridor Program in 2006. Under the National Biological Corridor Program, the long-running Payment for Environmental Services Program was newly prioritized into biological corridors throughout the country. The National Biological Corridor Program caused a nationwide spatial shift in placement of payments for environmental services throughout Costa Rica. We classified ASTER 15-m resolution imagery in a central Costa Rica corridor connecting the eastern and western protected areas networks to analyze the change in forests during the National Biological Corridor Program with its targeted payments for environmental services effort. We used object-based classification methods, and compared land cover changes over an initial four-year period of corridor policy enactment. We calculated the changes within PES properties and outside of PES regions, and we also calculated forest patch metrics during the same time period. Results indicate a decline in forest cover over the study period, along with an increase in urban and pasture land covers, with higher change and loss of forest centered inside of the biological corridor, near the construction area for the new San Carlos highway, and within eastern pasture areas. We also saw a higher percentage of forest loss inside of the biological corridor area as compared to areas outside of the biological corridor. Forest loss was drastically less within current and historic PES properties, as compared to the overall study region. Across the entire study region, patch metrics show a decrease in the number of patches and a slight decrease in average patch size. These results suggest that current and past designation of PES prevents forest loss within PES properties while the current designation of priority conservation status via the National Biological Corridor Program is not increasing connectivity and forest conservation. This is shown by increased land use change and a decrease in forest associated with biological corridor designation. These results are antithetical to the goals of the National Biological Corridor Program.

1. Introduction

Land conversion and deforestation are closely linked to agriculture throughout much of the world, and within Latin America these drivers have resulted in increased isolation of protected areas (DeFries et al., 2005). Deforestation and land conversion are tied to losses in environmental services, and these services have been shown to benefit human and wildlife populations through mitigation of climate change, stabilization of water resources, and preservation of biodiversity (Foley et al., 2007). Governments and other entities attempt to thwart deforestation and the loss

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of environmental services through conservation policies, such as neoliberal modeled Payments for Environmental Services (PES) policies (Pagiola, 2008; Wunder and Albán, 2008). PES is a system where outside benefiters of environmental services pay local communities or landholders to manage their properties to provide those environmental services, either through restoration or protection (Wunder, 2005). While many countries in Latin America have experienced forest loss, Costa Rica has seen an increase in forested areas, starting in the 1980s, with 2010 forest coverage totaling ~52% (Aide et al., 2013; FONAFIFO, 2012).

Costa Rica is proactive in developing environmental policies to preserve and conserve natural resources. In 1996, Costa Rica established the national PES program, under Costa Rica Forestry Law No. 7575. The goal is to promote watershed stability, biodiversity protection, scenic beauty, and carbon sequestration. This voluntary program solicits applications from landholders with properties that promote conservation, including protection of primary forests, reforestation, or agroforestry; and in return, these registered lands provide environmental services. Well defined land tenure and transparent actors make this system function within the PES framework (Sunderlin et al., 2009). Many entities, including beneficiaries of the environmental services as well as polluters, pay into the program, including national hydroelectric interests and the World Bank (Pagiola, 2008). Primary forest payments are eligible for renewal every five years, and agroforestry and reforestation are allowed one contract for five years, with no renewal. Most reforestation contract holders have plans to sell the wood for timber after 15–20 years, while a few contract holders are using the payments to reforest the land permanently. Contract holders plant both native and non-native tree species. Some tree species include Teak (*Tectona grandis*), American mahogany (*Swietenia humilis)*, Rainbow eucalyptus (*Eucalyptus deglupta*), Melina (*Gmelina arborea*), and Almendro (*Dipteryx panamensis*). Timber products in Costa Rica include wood for pallets or furniture, among others (Floors, 1997).

Jointly aligned with the PES program, the National Biological Corridor Program (NBCP) of Costa Rica was established in 2006 through Executive Order 33106 by the office of the Ministry of Environment, Energy and Telecommunications (MINAE) (National System of Conservation Areas SINAC, 2009; Villate et al., 2009). The stated goals of the NBCP are to achieve connectivity among neighboring protected areas and to increase biodiversity through sustainable use (SINAC, 2008). The NBCP aims to strengthen existing protected areas, using spatially targeted PES as a tool inside of biological corridors to increase forest cover and connectivity, as well as by supporting cooperatives and local groups to enhance stakeholder alliances and sustainable development in the biological corridor network (National System of Conservation Areas SINAC, 2009; Vargas, 2014). Along with biological corridors, other priority areas for targeted PES include the Huetar Norte Forest Program region, areas designated for protection of water resources, areas with a Social Development Index of less than 40%, and lastly, areas with expiring PES contracts (Wunscher et al., 2006).

Costa Rica ranks in the top 20 most biodiverse countries in the world, with 0.03% of the earth's land surface holding 4% of the world's species (INBio, 2015). Biological corridors and connectivity are integral components to the overall protection of biodiversity, reducing extinction rates from restricted gene flow due to fragmentation and decreasing the impact of stochastic disturbances acting on isolated populations (DeClerck et al., 2010; Hodgson et al., 2011). The Costa Rican biological corridors are embedded within the multinational Mesoamerican biological corridor, which was created in 1998 and runs through eight countries from Mexico to Panama (Miller et al., 2001). Costa Rica has 47 proposed biological corridors, covering 35% of the country, and in 2010 had 24 active biological corridors, each facing unique conservation challenges (DeClerck et al., 2010). Many of the Costa Rica biological corridors are composed of agricultural matrices, encompassing all forms of land use from private farms to government hydroelectric projects. Extensive human habitation, with its variety of land uses, causes heterogeneous patterns of human pressures within these corridor matrices.

The Paso de las Nubes Biological Corridor (CBPN) is a critical connection point for the eastern and western transects of the greater Mesoamerican corridor within Costa Rica, and is important for national protected area connectivity (Fig. 1). Located northwest of the capital of San José, this corridor serves as the northern-most corridor connection for protected areas on either side of the continental divide, and is the main corridor linking the northwestern dry forests to the eastern slopes. The CBPN encompasses a large altitudinal gradient, ranging from 300 to 2100 m above sea level, making the CBPN well-suited for the protection and persistence of biodiversity in the face of a changing climate (Becker et al., 2007; Loarie et al., 2009). Lastly, this biological corridor and neighboring protected areas serve as the headwaters for more than five major rivers that provide drinking water for cities throughout northern and central Costa Rica. The Juan Castro Blanco National Park on the eastern border is even named "The Park of Water", because of the wealth of rivers originating within its bounds.

The NBCP utilizes the conservation strategy of land sharing to foster connectivity. Land-sharing studies have shown the importance of remnant forests contained in a permeable agricultural matrix (Daily et al., 2003; Horner-Devine et al., 2003; Perfecto and Vandermeer, 2010). This matrix is composed of agricultural production areas, human settlements, agroforestry, and remnant forests, and these matrices can function as habitat or as a corridor system linking distant protected areas (Baum et al., 2004; Nagendra et al., 2013; Perfecto and Vandermeer, 2002). The existence of Costa Rican protected areas has been shown to decrease deforestation in areas directly outside of protected area boundaries, further aiding in connectivity and enriching the agricultural matrix (Andam et al., 2008). Along with connectivity, the agricultural matrix can provide environmental services to local human populations, and these services are rewarded through the PES program (Jauker et al., 2009). The maintenance of biological corridors within the agricultural matrix is essential for effective management of protected areas, biodiversity, and environmental services.

Within the matrix, some wildlife species are able to persist and travel, but many forest dependent species cannot cross large stretches of open lands between protected areas (Daily et al., 2003; Tabarelli et al., 2010). Within Costa Rica, the majority of large-bodied forest dependent mammal species are nationally endangered due to loss of habitat and hunting (Elizondo and Humberto, 1999). Within the Mesoamerican multi-national corridor, Costa Rica has one of the highest percentage of land held within protected areas at 26% (World Bank., 2015), but even with large areas under protection, connectivity is key for the utility of protected areas for wildlife species. The CBPN is essential for the movement of species requiring large home ranges or long dispersal distances. Male jaguars (*Panthera onca*) have a home range between 40 and 83 km^2, while male puma (*Puma concolor*) require a home range of 200–800 km^2, and male ranges rarely overlap (Rabinowitz and Nottingham, 1986; Reid, 1998; Soisalo and Cavalcanti, 2006). Even small carnivores such as the jaguarundi (*Puma yaguarondi*) require home ranges of up to 20 km^2 (Michalski et al., 2006). Neighboring protected areas do not have sufficient area to cover the home range of one individual male puma. Thus, the CBPN acts as a buffer zone to the extensive adjacent protected areas of Juan Castro Blanco National Park (145 km^2), Alberto Manuel Brenes Biological Reserve (78 km^2) and Monteverde Cloud Forest Reserve (260 km^2), further extending essential habitat for wildlife species (Fig. 1).

The value of natural experiments is indispensible in understanding the utility of conservation programs. Conservation policies must

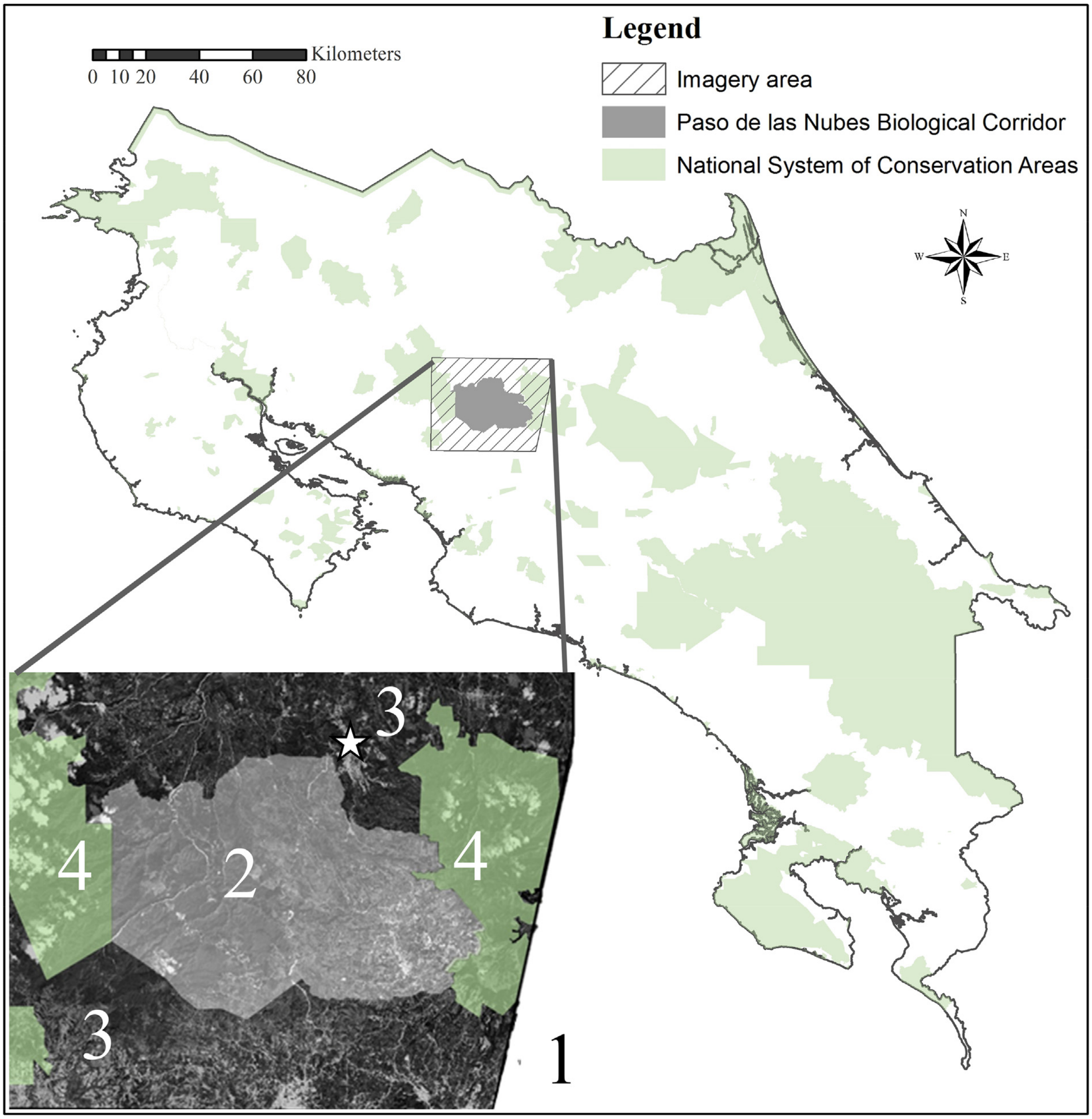

Fig. 1. Regional overview, with Paso de las Nubes Biological Corridor and imagery areas outlined. Change analysis areas are found in the lower left corner of the figure. Area 1 encompasses the entire imagery area; area 2: the biological corridor; area 3: the private lands outside of the biological corridor; area 4: the protected areas network, with eastern Juan Castro Blanco and western Manuel Brenes, Monteverde and Arenal Protected Areas. Star designates Ciudad Quesada.

be researched in the same manner as ecological hypotheses, and made to answer the question of additionality; that is, “do interventions work better than no intervention at all?” (Ferraro and Pattanayak, 2006). This is exactly what we aim to understand in this study. The study area enables us to examine changes seen under active conservation programs within the CBPN, and we designated a control area outside of biological corridor that currently does not hold priority and since 2006 holds lower probability of receiving PES contracts. While it can be challenging to link changes back to specific policies, identifying changes can provide a quantitative measure to determine if the goals of the conservation policies are being achieved (Ferraro and Pattanayak, 2006).

Assessment of the viability of the NBCP, with its large and complex spatial scale, requires landscape level analyses. While there are initial reports on ecological connectivity and diversity within biological corridors, no study has looked at the effectiveness of targeted PES within biological corridors (Céspedes et al., 2008; National System of Conservation Areas SINAC, 2009; Vargas, 2014). With the spatial complexity, remote sensing provides an effective measurement tool to assess these conservation measures, and can be used in future studies to map other corridors within the biological corridor network through the nation.

We took advantage of this natural landscape experiment to assess landscape changes temporally aligned with initial enactment of the National Biological Corridor Program, specifically on land use change within the CBPN. This information is a necessary assessment of this new targeting program, especially for government agencies and NGOs operating within the country, and in other counties utilizing targeted PES for corridor establishment. The objectives of this study were to: (1) identify the major land shifts, pixel by pixel, within the biological corridor; (2) understand how implementation of PES policies overlap with the changes in the corridor from years 2008–2012, with dates also determined through availability of cloud-free imagery; (3) identify land use changes and proportional changes within the CBPN as compared to similar areas directly outside of the corridor region, to understand the changes and pressures geographically aligned with and without PES targeting; (4) describe changes to forest patch metrics from 2008 to 2012, during the initial years of the NBCP within CBPN.

2. Methods

2.1. Study area

The CBPN is located in the Tilaran and Central mountain ranges of Costa Rica, in Alajuela Province. The corridor is comprised primarily of privately held lands and encompasses an area of ~40,000 ha. Life zones in the region include premontane rain forest, premontane wet forest, lower montane moist forest, lower montane rain forest, and tropical wet forest (Hartshorn, 1983). The primary land uses consist of forest, dairy farms, ornamental plant farms, tree plantations, urban areas, and rural towns. The CBPN is bordered to the east by Juan Castro Blanco National Park, and to the west by Alberto Manuel Brenes Biological Reserve and Monteverde Cloud Forest Reserve. North of the corridor, there is extensive agriculture and one of the largest cities in the region, Ciudad Quesada. South of the corridor lies many cities emanating from the capitol, including Naranjo de Alajuela and San Ramon, and extensive agriculture, with a wealth of coffee plantations to the southeast.

Before 2006, landholders within the CBPN bounds had an equal opportunity of being selected for PES as compared to areas outside of the not-yet designated CBPN. In 2007, PES priority was moved inside the bounds of the biological corridors, leaving areas outside of the corridor at a lower priority for payments. When looking at general national forest trends, between 2001 and 2005 (before the NBCP) there was a national loss of approximately 63,000 ha of forest (Global Forest Loss, 2015), and within Alajuela Province, there was a loss of 15,878 ha (−1.32%) of forest. From 2001–2012 there was an overall gain of 7,162 ha of forest (Global Forest Loss, 2015).

PES properties were diverse within the study region. Registered PES contracts under the 2003–2014 period were as follows; 212 forest protection property contracts, 40 agroforestry contracts, and 13 reforestation contracts (Table 1). Forest protection contracts had the highest average property size, and maximum area, while reforestation had the lowest (Table 1). Economic activities conducted by PES property owners were diverse, and included dairy cattle farms, ornamental plant production, subsistence farms, timber trees, ecotourism, and other employment based in the larger regional cities of Ciudad Quesdad and San José. Around one-fourth of PES contract holders lived on the property, while the other fourth lived off site with managers living on the property. Half of the properties were forest plots with no housing, land managers, residences, or roads.

2.2. Pre-processing

To quantify land use change, we first acquired Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery from February 2nd, 2008, and February 29th, 2012. We selected dates based on the timing of corridor policy enactment, and for low cloud cover across the CBPN. No other imagery dates with 15-m resolution (Landsat or ASTER) had less than 30% cloud cover over the CBPN within any season near the implementation of the CBPN or current day. Thus, the two images acquired were the only two available with less than approximately 30% cloud cover over the CBPN and usable for this analysis. Although we did not acquire imagery from the first year after implementation, 2007, we felt the imagery from 2008 was the next best option. Images were from the dry season and within the same month (February) to allow for vegetation comparability; the study area during the dry season received a monthly rainfall average of approx. 100 mm (http://soltiscentercostarica.tamu.edu/Resources/On-Line-Meteorological-Data). The imagery bands used for the analysis included the first three ASTER bands, visible green/yellow, visible red, and near-infrared, with 15-m resolution. We used four imagery tiles in this study, two from 2008, and two from 2012, all from ASTER satellites from the approximate location of path 15 and row 53.

During pre-processing, we orthorectified each image, accomplished with the use of software SilcAst with Global ASTER DEM version 2. Then, the imagery was clipped to encompass the corridor, and included private lands within a 6.7 km buffered region around the corridor. This clipping extent was based on the size of the imagery and the accuracy for which the classification could be conducted; areas outside of that buffered region had different vegetation signatures based on mirco-climates causing discrepancies with classification and were not important for our analysis, and thus were removed from the analysis. To discriminate between areas of active vegetation growth and senescent or bare land, we calculated the Normalized Difference Vegetation Index (NDVI) by subtracting the red band from the near infrared band, and dividing that value by the near infrared band plus the red band ((nir-r)/(nir+r)) (Carlson and Ripley, 1997). We also generated a texture band to create a filter, using the co-occurrence tool in the software ENVI (ENVI version 5.2, 2014). The texture band created from the yellow/green band was deemed the most useful in detecting differences in vegetation and non-vegetation. We stacked the texture band with the NDVI layer and the three ASTER bands to produce a pre-processed imagery product with five layers (Appendix A1 in Supplementary material).

2.3. Processing

We conducted an object-oriented classification of the imagery using Trimble eCognition Developer 9.1 (Trimble, 2011). We chose to use object-oriented classification as opposed to pixel-based classification because initial trials using pixel-based methods produced low accuracy and kappa values. Other studies have also shown that object-oriented classification can result in higher accuracy as compared to traditional pixel-based classification (Platt et al., 2008). The parameters developed for our rule set were as follows: scale parameter: 5, shape parameter: 0.1, and compactness: 0.9. Each layer was weighted equally for segmentation, with a value of 1. Segmentation parameters included the nearest neighbor feature objects with

Table 1
PES contract information for participants within the study region.

PES Land Use (2003–2014)	Total Area (km^2)	Maximum Contract Area (km^2)	Total number of Properties	Average Property Size (km^2)
Reforestation	2.762	0.551	13	0.197
Agroforestry	17.283	3.177	40	0.432
Forest Protection	193.750	7.998	212	0.884

Table 2
Confusion matrix for 2008 and 2012 classification of imagery, including user and producer accuracy, kappa coefficients, and overall accuracy.

Class	2008−1		2008−2		2012−1		2012−2	
	Producers	*Users*	Producers	*Users*	*Producers*	*Users*	*Producers*	*Users*
Forest	98.61	97.26	96.30	96.30	90.97	93.33	95.24	97.56
Bare land	91.43	100.00	97.50	90.70	70.73	61.70	92.73	87.93
Pasture	100.00	94.74	100.00	87.23	90.91	90.91	92.68	100.00
Low vegetation	98.68	97.40	95.00	97.44	94.68	93.68	100.00	92.50
Water	100.00	100.00	100.00	100.00	88.89	100.00	93.02	100.00
Urban	95.00	98.70	87.84	100.00	78.05	84.21	95.65	96.70
Cloud/shadow	100.00	97.50	97.50	96.30	100.00	94.74	98.92	95.83
Overall accuracy (%)	97.82		95.70		89.22		95.73	
Kappa Coefficient	0.9740		0.9489		0.8717		0.9490	

mean and standard deviation. After this rule-set was developed, we segmented the imagery tiles (Appendix A1 in Supplementary material).

After segmentation, we identified nine classes based on the vegetation and pixel characteristics of the imagery. The vegetation classification categories included: (1) urban or built up land, (2) pasture, (3) low vegetation, (4) bare ground, (5) forest, (6) dark forest, (7) clouds, (8) cloud shadows, (9) pacific slope low vegetation, (10) water. After classification, we merged classes that represented identical on-the-ground land cover types including pacific slope vegetation and low vegetation classes, cloud and cloud shadow, and forest and dark forest classes. Pacific slope vegetation represented vegetation below 2.5 m in canopy height located in a region with a distinct dry/wet season rainfall pattern, as opposed to the low vegetation on the Caribbean slope with more constant yearly rainfall. The dark forest class represented forest in shadowed slopes in mountain valleys.

2.4. *Field measurements*

We collected ground truth and training point data for all class categories except cloud, cloud shadow, and water. Field ground truth points were collected from May to August 2012–2014, and were collected from all regions of the biological corridor and areas outside of the corridor. Accessibility was the only limiting factor to these points. We collected ground truth points in areas with road networks or trails within properties. PES shapefiles from FONAFIFO (Fondo de Financiamiento Forestal), along with satellite based imagery, were also used to provide additional ground truth points for years 2008 and 2012, especially in regions of the study area with few roads or difficult accessibility. Due to the steep mountain topography of the high-altitude stream and river channels in the CBPN, we can predict that the streams and rivers have not migrated over the short time scale of this study; because of this, we were able to visually identify water class regions. For both 2008 and 2012, we collected between 40 and 80 training samples, and approximately 55 ground truth points per class.

2.5. *Post-processing*

First, we conducted a post classification cleaning of all images by manual object identification and classification; this step was especially important for areas of high reflectance along the perimeters of clouds. Next we mosaicked the tiles for each year, conducted an accuracy assessment on the classified imagery, and calculated Kappa statistics (Table 2). The kappa values were 0.97 and 0.95 for 2008 and 0.87 and 0.95 for 2012. The overall accuracy for 2008 was 97.82% and 95.70%, and for 2012, 89.22% and 95.73**%**. We found these kappa and overall accuracy values satisfactory to proceed with a change detection analysis (Table 2). The final classes for the imagery included forest, pasture, low vegetation, bare ground, urban, water, and cloud, with class descriptions in Appendix A2 in Supplementary material. Clouded areas from each classification were merged and masked before conducting the change detection. This removed the potential for comparison of cloud to non-cloud areas, eliminating cloud bias in the difference map.

2.6. *Change detection analysis*

We conducted a post-classification change detection analysis to understand the land use changes and to describe the anthropogenic activities occurring in the region during the initial years of the NBCP. A change detection comparison took place within three distinct spatial regions: (1) the entire study area, (2) only within the CBPN, and (3) lands directly outside of the biological corridor within the 6.7 km wide buffered area (Fig. 1). Region three, lands directly outside of the biological corridor, served as control regions to compare with the CBPN; these areas represented non-prioritization areas after NBCP enactment. Region three is composed primarily of private lands, with similar economic activities, and is approximately the same size as the CBPN, making it suitable for comparison. The change detection analysis provided information on the overall differences in land use from 2008 to 2012, and the conversions, pixel by pixel, from one land use category to another.

We then conducted change detection from 2008 to 2012 within regions of current and historic PES properties, analyzing PES contracts from 2003 to 2014. For a PES participant to continue in the program, PES properties were monitored yearly during active contracts, and the owners followed a number of regulations detailed in their contracts, including prevention of hunting, fires, and deforestation, among others (Pagiola, 2008). That said, we do not expect to see forest change during active contracts. However, changes can occur after contracts have expired, as the land uses are unrestricted and solely the landowner, not the PES program, makes the decisions.

2.7. *Forest patch metrics*

In conjunction with the change detection analysis, we calculated patch metrics for the forest class in 2008 and 2012 across the entire study region, including patch number, and average patch area. These metrics provided information on changes to forest patch dynamics to help understand movement ability of populations across a landscape (Gutiérrez et al., 1999; Hanski and Hanski, 1999; Lawes et al., 2000).

3. Results

3.1. *Classification results*

We developed a land-use classification map of the study area (Fig. 2). The most prevalent class across the entire imagery in 2008 (area 1, Fig. 1) was forest, at 399 km^2, and the next two largest classes were low vegetation (297 km^2) and bare ground (94 km^2).

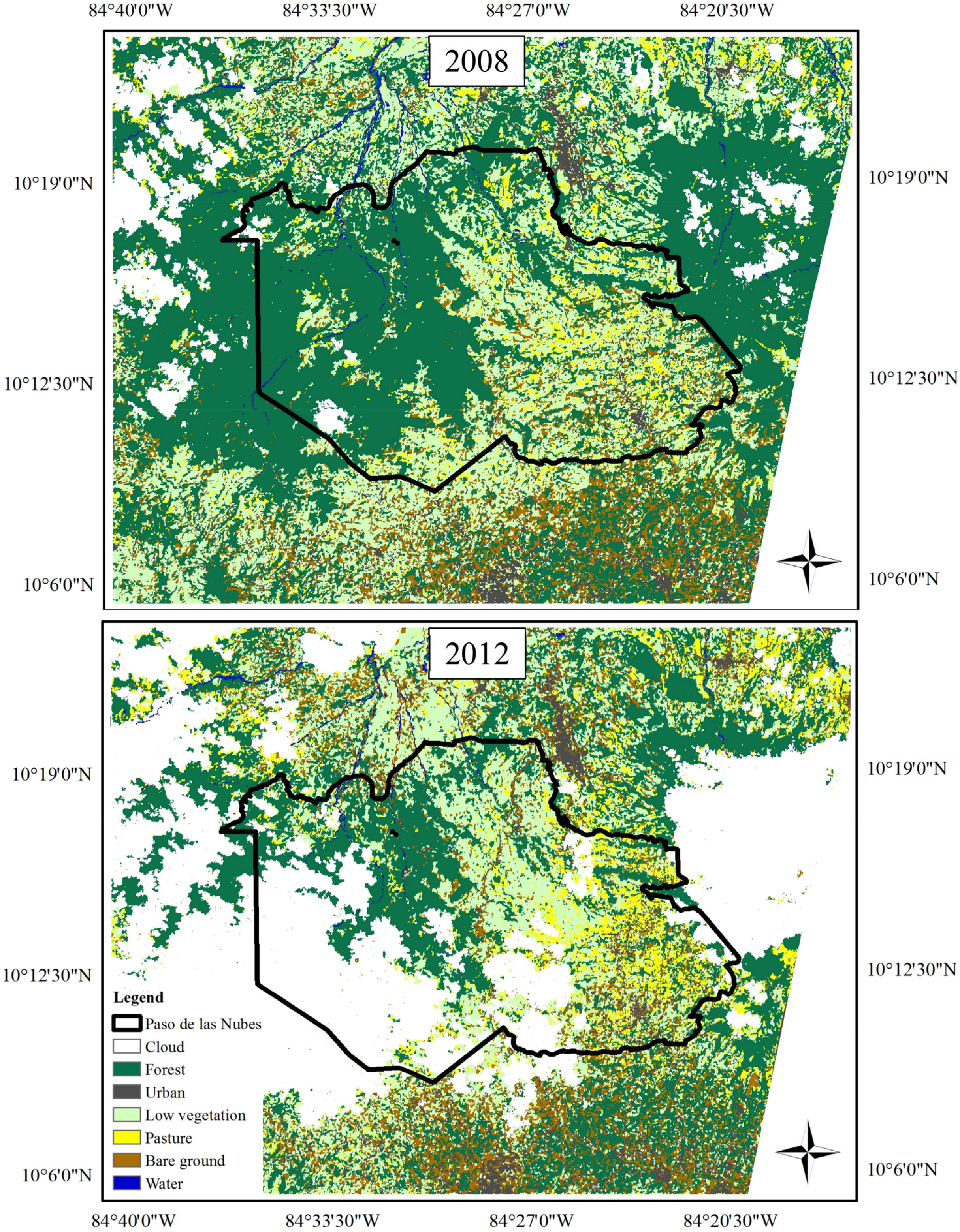

Fig. 2. Land use classification for 2008 and 2012, with the Paso de las Nubes Biological Corridor outlined in black. The bare ground and urban linear feature in the center of the 2012 map is the construction of the San Carlos highway, and Ciudad Quesada is the grey urban oblong polygon just to the north of the Paso de las Nubes Biological Corridor border.

Urban areas covered 56 km^2 (Table 3). In 2012, forest again was the most prevalent class; with 355.75 km^2 followed by low vegetation and bare ground (Table 3). Within the CBPN in 2008 (area 2, Fig. 1) forest totaled 130.48 km^2, declining to 103.68 km^2 in 2012; low vegetation and pasture were also the second and third largest cover types in 2012, with low vegetation at 9% (34 km^2) and pasture at 23% (95 km^2). While the CBPN does have a number of towns and cities located within the boundary, the urban areas were rel-

Table 3

Change detection, with values representing change in each land use category, within each spatial change analysis area, as determined by the remote sensing analysis. Numbers for the change analysis area represent: 1. Entire imagery area; 2. Biological corridor area; 3: Areas outside of biological corridor, excluding protected areas network.

Change analysis area		Cloud	Forest	Urban	Low vegetation	Pasture	Bare	Water
1	Total image area 2008 (km^2)	501.53	399.85	55.84	297.39	49.40	94.23	5.58
1	Total image area 2012 (km^2)	501.53	355.75	61.21	283.04	79.45	117.98	4.56
1	Difference in total image area (km^2)	–	−44.10	5.36	−14.35	30.05	23.75	−1.03
1	Difference total image area (%)	–	−11.03	9.61	−4.83	60.84	25.21	−18.36
2	Paso de las Nubes 2008 (km^2)	134.15	130.48	8.43	89.77	20.16	19.01	1.19
2	Paso de las Nubes 2012 (km^2)	134.15	103.68	12.53	95.54	34.44	22.30	1.15
2	Difference Paso de las Nubes (km^2)	–	−26.80	4.10	5.78	14.28	3.30	−0.05
2	Difference Paso de las Nubes (%)	–	−20.54	48.59	6.44	70.83	17.36	−3.85
3	Private Lands Outside Paso de las Nubes Biological Corridor 2008 (km^2)	153.92	193.30	46.25	189.83	26.07	69.89	4.22
3	Private Lands Outside Paso de las Nubes Biological Corridor 2012 (km^2)	153.92	178.85	46.88	171.90	38.29	91.31	3.23
3	Difference Private Outside Paso de las Nubes Biological Corridor (km^2)	–	−14.45	0.63	−17.93	12.22	21.42	−0.99
3	Difference Private Lands Outside Paso de las Nubes Biological Corridor (%)	–	−7.48	1.36	−9.45	46.88	30.64	−23.49

atively small, 8.43 km^2 in 2008 and 12.53 km^2 or 3% in 2012. The majority of the land throughout the biological corridor was forest and low vegetation, and both land uses were eligible for PES forest or reforestation payments, while only a small percentage of CBPN was comprised of permanently built up lands (Table 3).

3.2. Change detection results

When focusing across the entire extent of the imagery (area 1, Fig. 1), we observed the largest change in area from 2008 to 2012 in the forest class, with a loss of 44 km^2, or an 11% decrease in forest, corresponding with a 30 km^2 gain in pasture. The largest proportional gain was in pasture, with an increase of 60%. We also observed an increase in bare ground (23 km^2 or 25%) and urban (5.36 km^2) (Table 3).

Within the CBPN (area 2, Fig. 1), we observed the largest change in area in the forest class, with a loss of 26 km^2 paralleled by a gain of 14 km^2 in pasture. We also saw minor gains in bare ground, low vegetation and urban areas (3 km^2, 6 km^2, and 4 km^2, respectively). When considering the percentage change, the largest change was observed in pasture with a 70% gain, followed by a 20% loss in forest and a 17% gain in bare ground (Table 3).

The private lands outside of the CBPN but within the 6.7 km buffered area (area 3, Fig. 1) had the largest changes in the bare ground class, with a gain of 21 km^2, followed by a loss of 18 km^2 in low vegetation. We observed a similar gain in pasture and loss in forest, at 12 and 14 km^2, respectively. The largest percent change occurred in the pasture class with an increase of 47%, followed by a 30% gain in bare ground.

When concentrating specifically on the forest class, we observed negative changes in forest cover both inside the CBPN (area 2, Fig. 1) and throughout private lands outside of the corridor (area 3, Fig. 1). The CBPN exhibited a larger reduction in forest than the surrounding private lands; inside the corridor there was a 27 km^2 loss of forest (-20.5%) while private lands outside of the corridor experienced a loss of 14 km^2 of forest (-7%). Both areas experienced gains in pasture, bare ground, and urban regions, with larger percentage gains in urban areas inside of the corridor (Table 3).

Within the CBPN (area 2, Fig. 1), changes were concentrated in gains of pasture and losses of forest, especially along a strip through the center of the 2012 map (Fig. 2). This faint bare ground and urban strip bisecting the CBPN is the construction and development pathway of the San Carlos highway, with planned completion in 2016 or 2017. Additionally, there was forest loss on either side of the highway (Fig. 2).

While IRB (#IRB2012-0439) regulations do not allow linking landholders to spatial data, we reported the changes seen within the three forms of PES properties compared to non-PES regions (Table 3). All PES regions had slight losses in forests (Table 4), but these losses, by percentage and area, were substantially less than non-PES regions. Percent change in forest protection PES ranged from between −0.17 to −7%, with reforestation PES regions showing the least amount of forest loss at −0.17%, and forest protection regions showing the highest forest loss at 7% (Table 4). We see gains in urban, pasture and bare for all three PES regions, but areas are small when compared to non-PES regional gains, with PES gains in pasture, urban and bare at below 2.6 km^2, with most gains at less than 0.1 km^2 (Table 4).

Lastly, forest patch metrics were reported for 2008 and 2012. There were 4371 forest patches across the entire imagery area (area 1, Fig. 1) in 2008, while in 2012 we saw a decrease in forest patches to 3698. The average patch size increased slight from 9.18 km^2 in 2008 to 9.62 km^2 in 2012. Within the CBPN we saw forest patch number decrease from 1325 in 2008 to 1078 in 2012. Average patch size within CBPN decreased from 10.03 km^2 to 9.76 km^2.

4. Discussion

Additionality is used to measure effectiveness of conservation programs, and is defined as the conservation effects as compared to baseline outcomes (Wunder, 2007). We saw little additionality during the initial years of NBCP enactment, demonstrated by decreased forest cover despite connectivity goals and an increased effort to target conservation using PES inside the CBPN. Forest decreased across the entire landscape, both inside and outside of CBPN, indicating a regional transition in forest cover, but with percent loss in forest almost three times higher inside the CBPN (Table 3). We did see additionality within PES property bounds, with substantially less forest change within PES regions as compared to non-PES regions. And while it can be challenging to link landscape changes

Table 4

Change detection for PES regions, with values representing change in each PES payment type, reforestation, forest protection (forest), and agroforestry. Land use categories are shown within each spatial change analysis area, as determined by the remote sensing analysis. Both percentage change and area gained or lost are shown in the table.

Difference in PES areas 2008–2012	Forest	Urban	Low vegetation	Pasture	Bare	Water
Reforestation (km^2)	−0.0013	0.0410	0.0855	0.0090	−0.0045	−0.0025
Reforestation (%)	−0.17	379.17	18.78	12.09	−5.08	−50.00
Forest (km^2)	−4.1418	0.2533	2.5542	1.8266	2.5747	0.0817
0Forest (%)	−7.23	33.02	18.24	84.20	197.50	47.20
Agroforestry (km^2)	−1.1147	0.0504	1.1439	−0.1870	0.0000	−0.0018
Agroforestry (%)	−17.88	22.95	33.11	−32.41	235.91	−9.64

back to specific policies, identifying landscape changes can provide a quantitative measure to empirically determine the success or attainment of policy goals and conservation efforts (Ferraro and Pattanayak, 2006). We found PES protects forests, but these protections do not extend to other lands outside of the PES property bounds to fulfill the larger NBCP goals.

Past studies have questioned the additionality of Costa Rica PES and deforestation ban programs against baseline scenarios, citing little change in deforestation rates with or without the policy (Miranda et al., 2003; Sanchez-Azofeifa et al., 2007; Sierra and Russman, 2006). Specific concerns include payment to lands already destined to be protected while using limited conservation funds (Miranda et al., 2003; Pagiola, 2008). A recently study on the forestry ban of 1996 actually showed an increase in forest. Fagan et al. (2013) described that while perverse incentives could have acted to decrease natural regeneration, instead, as intended, forest area increased. In our study, we also found benefits to PES, in the form of decreased forest lost in current and historic PES regions.

Within the biological corridor, economic pressures and road networks could be a major driving factor in forest loss outside of PES properties, countering conservation efforts (Geist and Lambin, 2002). The construction of the San Carlos highway is funded and designed by the government agency CONAVI with supplemental funding from the dairy cooperative Dos Pinos (Fig. 2) (Herrera, 2011); Dos Pinos owns a dairy factory in Ciudad Quesada, with another plant south, near San José. Dos Pinos is one of the main economic interests in the area, and supplies the country with dairy products. It is also worth noting that many Dos Pinos farmers are participants of the PES program, and hold important forest patches on the eastern side of the corridor. The new highway is a four-lane route able to move agricultural products from the agricultural regions in northeastern Alajuela, Heredia and Limon provinces to the western and central parts of the country, with future increased access to markets. Currently, two 2-lane highways run the length of this 20 km-wide sensitive CBPN area, with the new San Carlos highway located in the middle, placing each route approximately 7 km apart, all with similar geographical origins and ends. The necessity for the new highway is questionable if current highway routes had been expanded, however the San Carlos highway is in its final years of construction after approximately 40 years of planning. As such, once the highway is completed, ease of access to forests and the interior of the biological corridor will increase, and without sufficient conservation tools in place, we can predict additional urbanization and deforestation in these newly opened areas. Dos Pinos is unofficially linked to the conservation efforts in the CBPN with many of their dairy farmers receiving payments through the PES program, especially along the eastern side of the corridor. Dairy farmer participation could be used as a catalyst to grow an official conservation partnership with the dairy cooperative, the NBCP, and the PES program, working towards conservation goals in the corridor.

Focusing further on potential cooperative efforts, the NBCP and PES programs, officiated by both SINAC and FONAFIFO, and the highway system run by CONAVI, are all government agencies and programs, with funds that appear to be working without coordination. This misalignment is exemplified within the CBPN, with CONAVI's highway construction working to the detriment of SINAC and FONAFIFO's funds to promote connectivity and ecosystem services. To eliminate contradictory outcomes in funding, government agencies working within similar geographical areas could create formalized collaborations (the fourth goal of the NBCP) to define solutions and mitigate conflicting goals, such as the situation currently occurring in the CBPN.

Perverse incentives are a concern within many conservation payment programs. Designation of conservation priority lands can in some cases cause the opposite of the desired conservation actions, leading to unintended or perverse consequences such as land grabs, habitat degradation, or in-migration (Liu et al., 2007; Rodriguez-Solorzano, 2014). In the neighboring biological corridor of San Juan/La Selva, landowners have expressed anger around corridor designation. In contrast, when interviewing PES landowners in the CBPN, most were not aware that their properties were located within a biological corridor, but showed positive interest in the designation. This unawareness could be partially attributed to the fact that we witnessed no official signage designating the CBPN. And while perverse incentives were observed in other studies (Rodriguez-Solorzano, 2014), we feel that the designation of the biological corridor did not lead to deforestation and conversion of land through these means. Additional signage and public campaigns delineating the CBPN may even spur collaborations among interested actors within communities.

While forest loss was not linked to perverse incentives, the loss of forest in the CBPN did cause a decrease in the quality of the countryside matrix, resulting in a less permeable landscape for wildlife species and less density or width of movement corridors throughout the region (Daily et al., 2003). There is also a decrease in the size and number of forest patches, increasing the distance required to travel between and among patches. Some species or individuals may not be able to move to or from spatially isolated patches. Further isolation of these patches can negatively impact remnant populations that are dependent on forests for habitat (McGarigal et al., 2009), degrading the quality and conservation potential of this area, antithetical to the goals of the NBCP.

Wunder (2005) describes PES as a valid conservation tool when threats are intermediate, when projected as a future threat, or when land use choices are flexible. Intermediate threats can be defined as mid-level deforestation rates. In our study region, land uses are not flexible due to the deforestation ban, and the region holds immediate threats such as the opening of the middle of the corridor with the new highway, in an area deemed a high priority for conservation. While this study area meets some of the PES recommendations, in this situation, PES has been shown to protect forests across the study region, with areas outside of the PES properties (falling under the NBCP) experiencing the highest losses in forest cover. The current situation in the CBPN is a case for effective application of a systematic conservation planning process (Margules et al., 2007) to generate optimal solutions using economic costs and benefits under the current constraints.

Under future planning processes, PES and biological corridor policies could spatially target reforestation and forest protection payments to accomplish the stated goal of the programs. This can occur in a variety of ways. Programs could focus on specific areas with high forest loss and solicit applications from specific farms and regions. There could prioritize recently deforested areas near the highway, allowing for renewed connectivity of neighboring mammal populations with short isolation times. This may be beneficial as forest fragments isolated for longer periods may have higher local extirpation of species. This would also provide PES protection to the newly accessible core areas of the corridor using a forest buffer along the highway route. Lastly, within the CBPN, barrier issues tied to highway development could be mitigated through the use of culverts or overpasses.

5. Conclusions

Costa Rica leads among Central American countries in protected area coverage, and has been proactive in staving off deforestation and degradation of the agricultural matrix since the 1980s. The corridor system exemplifies a policy priority of conservation and connectivity. While our study reveals that PES properties within the corridor provided protection against forest loss, we found that even with official biological corridor designation, non-PES lands within corridors can experience increased land use change and forest loss. The reasons for these changes are varied and complex. Biological corridors are an essential link for the protected areas network in Costa Rica and for greater connectivity throughout the Mesoamerican biological corridor. The Biological Corridor system is a unique and an exceedingly important piece of legislation, for which the goals to enact important conservation measures must be accomplished. Policies and on-the-ground outcomes must be reviewed to understand the drivers of change and the requisite tools needed to accomplish these important goals.

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