FOREST CONSERVATION TARGETING TOOL (FCTT)
VERSION 1.3

METHODS AND DATA

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Accessing the FCTT: The FCTT is available at: http://fc-targeting-tool.net, http://conservationroi.net and http://fctt.servirglobal.net

A. Background

According to United Nations Food and Agriculture Organization, the rate of deforestation in tropical countries remains "alarmingly high." In Latin America, it averaged one-half of one percent per year in the first decade of the 2000s, five times the global rate. This deforestation, along with forest degradation, has contributed to a host of local and global environmental problems, including soil erosion, water pollution, biodiversity loss, and greenhouse gas emissions.

Unfortunately, the financial and human resources available to address this problem are limited. In many countries, unsustainable deforestation and degradation are widespread geographically, but regulatory agencies, nongovernmental organizations, and other policymakers do not have the funds or personnel to invest in programs and projects that cover all of their forested areas.

Therefore, policymakers must choose where to invest. For example, they must choose where to establish protected areas, where to set up payments for environmental services initiatives, where to provide forest management extension services, and where to promote forest certification.

How should stakeholders make these choices? That is, how should they target forest conservation investments? A critical input into such decisions is an understanding of where forest conservation will generate the greatest possible the greatest possible conservation benefit per dollar spent (bang-for-the-buck).

Such information is particularly important in the context of Reducing Emissions from Deforestation and Degradation (REDD+) which makes funds available to developing countries conditional on verifiable reductions in forest carbon emissions. Decisions about investing REDD+ resources can benefit from an understanding of how conservation benefits per dollar spent vary across forests.

B. Goal

The goal of the Forest Conservation Targeting Tool (FCTT) is to provide the data and analysis that policy makers need to geographically target conservation investments so as to maximize their bang-for-the-buck, or more technically, their expected conservation benefit per dollar spent.

C. General method

The FCTT aims to inform forest conservation targeting decisions by

- displaying fine-scale spatial data on the three key drivers of conservation bang-for-the-buck: (i) deforestation risk, (ii) forest ecosystem services, and (iii) conservation costs;
- using these three types of data to calculate a single measure of expected conservation benefit per dollar spent for each parcel of forest in a user-defined study area; and most important
- identifying the forest parcels in the study area that generate the greatest bang-for-the buck.

D. Geographic scope

The FCTT's current geographic scope is Mexico, Central America, the Dominican Republic, and South America.

E. Spatial unit of analysis

The spatial unit of analysis that FCTT employs is flexible, and can be determined by the user. For regions where cadastral data are available, it is a forest management unit defined by such data. Everywhere else, it is a simple $10km^2$ cell, a simple $1km^2$ cell, or (for Central America only), second-level administrative units. The current version of FCTT only has cadastral data for Mexico. In that country, the unit of analysis is a *predio* (property). Most forested *predios* are either communally held (*ejidos* and *comunidades*) or are privately held. A small proportion of forested predios are state-owned.

Computational constraints limit the maximum size of the study area when $1km^2$ cells are used as the spatial unit of analysis. Therefore, for large South American countries, we break up country-level $1km^2$ cell data sets into 46 smaller subdatasets, which are indexed in the Appendix. The FCTT can only run its targeting algorithm using on-board $1km^2$ cell-level data within a single subdataset. To perform targeting at the $1km^2$ cell-level in a South American study that spans the geographic boundaries of these subdatasets, users have two options: they can use predio or $10km^2$ cell datasets or they can employ the "Use Your Own Data" feature to import a suitably small $1km^2$ dataset that straddles the border of two of the subdatasets.

F. Model outputs

FCTT's principal output is the expected benefit per dollar of conservation investment (bang-per-buck) for each unit of analysis.

G. Model Structure

The expected benefit per dollar of conservation investment (bang-per-buck) in a given unit of analysis ("unit" for short) is simply the risk of deforestation on the unit times the ratio of the total benefit of conservation on the unit to the cost of conservation on the unit. That is,

$$EBC_p = \frac{R_p * B_p}{C_p} \qquad (1)$$

where

p	indexes units
EBC	is expected benefit per dollar (or peso)
R	is deforestation risk
B	is total conservation benefit
C	is conservation cost.

The reason for multiplying benefit/cost ratio by deforestation risk is that conserving forest in a given unit only generates *additional* benefits to the extent there is significant risk that the forest would be cleared or degraded absent the investment. For example, if we assume for simplicity that carbon is the only benefit, that a given unit contains 100 tons of forest carbon, and the risk of deforestation for that unit is 60 percent, then the expected benefit of forest conservation is 100 tons times 60 percent = 60 tons of expected avoided forest carbon emissions.

Total benefit, B_p, is the weighted sum of three separate types of ecosystem benefit that forests provide

- carbon storage
- provision of biodiversity habitat
- provision of hydrological services

More formally,

$$B_p = \sum_j w^j \frac{B_p^j}{B^j} \qquad (2)$$

where

j	= (c, b, h) indexes the type of ecological benefits: carbon storage (c), provision of biodiversity habitat (b), and provision of hydrological services (h)
w^j	is a weight for benefit type
B_p^j	is benefit type j in unit p
$\boldsymbol{B}^j$	is the median value of the benefit j across all units within an study area.

Without loss of generality, we assume the three weights sum to one. They reflect an inherently subjective judgment about the relative importance of the three benefit types. For example one policy maker might care only about carbon storage and not at all about biodiversity or hydrological benefits, in which case their weights would be ($w^c = 1$, $w^b = 0$, $w^h = 0$). FCTT users themselves must determine the weights for each benefit type, and are required to input that information into the webtool.

As discussed below, the three indices of ecological benefits are denominated in different units: carbon storage is measured in tons, provision of biodiversity habitat in numbers of species, and hydrological services in cubic meters squared. We normalize each index by its median value to make the magnitudes of the indices comparable.

Given these different units, our measure of expected conservation benefit per dollar spent in a given spatial unit, EBC_p, does not by itself provide meaningful information. Rather, EBC_p for a given unit is only meaningful when compared to those for other units. In that case, it gives an indication of the ranking of expected conservation benefit per dollar spent across units. In other words, EBC_p is a 'ordinal' measure, not a 'cardinal' one.

Having calculated an index of expected benefit per dollar spent for each spatial unit in a study area, the FCTT uses a simple 'knapsack' algorithm to select them. It ranks all units from highest expected benefit per dollar spent to the lowest. Then, starting at the top of the list, it selects units until a user-defined conservation budget is exhausted. The default budget is arbitrarily set at 10% of the conservation costs of all spatial units in a user-defined study area.

H. Data and methods for estimating components of expected conservation benefit per dollar

This section briefly describes the data and methods used to estimate deforestation risk, cost, and benefits. Table 1 summarizes the discussion.

Regarding the data, note that the FCTT allows users to substitute their own data layers for the on-board layers if they wish.

Table 1. Data and methods used to parameterize FCTT

Parameter	**Key data/model**	**Description of key data/model**	**Methods**
Carbon benefits (Mexico)	MREDD+ Alliance (2013)	$30m^2$ data on above ground carbon stocks in woody vegetation	Averaged over forest area of predio
Carbon benefits (Central Am. & D.R.)	GIZ (2014)	$30m^2$ above-ground and below-ground carbon stock in woody vegetation	Averaged over forest area of unit
Carbon benefits (South Am.)	Saatchi et al.(2011)	$1km^2$ data on above-ground and below-ground carbon stock in live biomass	Averaged within unit
Biodiversity benefits	IUCN (2013), Birdlife Int. (2012)	Species ranges for mammals, amphibians, reptiles and birds	Used to calculate a rarity weighted richness index for each unit: a weighted count of threatened species where weights reflect rarity of each species nationally or globally
Hydrological benefits	Mulligan (2013)	Integrated land-use/hydrological model	Used to generate a watershed-level index of the importance of tree cover to water balance (precipitation – transpiration) and water quality

Deforestation risk	Hansen et al. (2013)	$30m^2$ annual data on land cover change 2001-2012	Along other with geospatial data on land characteristics, used to econometrically estimate unit-level risk of deforestation on forested land
Conservation cost (Mexico)	SAGARPA (2011)	Predio-level data on hectares planted in 160 crops and hectares in pasture; county-level data on average yields and prices for crops, and revenues pasture	Used to calculate unit-level gross revenue from agricultural and pasture per hectare of forest
Conservation cost (Central Am., D.R., & South America)	Naidoo and Iwamura (2007)	5 min grid (9 km2) data on potential annual gross revenue from agriculture	Used to calculate unit-level gross revenue from agriculture per hectare of forest

1. Deforestation risk (*R*)

For each unit, we econometrically estimate deforestation risk as the annual probability that existing forests in the unit will be cleared. Our econometric model purports to capture the *past* relationship between deforestation and land characteristics that drive deforestation, including both: (i) time-invariant characteristics such as distance to population centers, soil quality, slope, altitude, land tenure, opportunity cost of forest conservation and demography; and (ii) time-varying characteristics such as annual rainfall, average temperature, and population density. We then use the estimated parameters from this econometric model to predict *future* clearing on forested land as a function of its characteristics.

They most important data in the econometric model are those on deforestation. We use fine-scale ($30m^2$ resolution) 2000-2012 annual land-cover change data (Hansen et al. 2013). For the study areas, these data contain millions of these pixels. We constructed a computationally feasible regression sample by overlaying a 1km rectangular grid onto the study area, and selecting pixels where the grid lines intersect. To construct spatial unit of analysis-level predictions, we average predicted probabilities for all sample pixels in each unit.

We experimented more a variety of specifications of our econometric model, and selected the one that preformed best in out-of-sample prediction. We calibrated our models using 2000-2009 data and validated them using 2010-2012 data.

3. Carbon benefits (B^c)

For Mexico, the carbon benefit of forest conservation is average per-hectare carbon content of above-ground biomass in each unit. We use estimates from a fine scale ($30m^2$) 2013 dataset from Woods Hole Research Center (MREDD+ Alliance 2013). Units are tons per hectare.

For Central America and the D.R., the carbon benefit of forest conservation is average per-hectare carbon content of woody biomass in each unit. We use a fine scale ($30m^2$) from GIZ (2014). Units are tons per hectare. Users may choose to use above-ground forest carbon, below-ground forest carbon, or both.

For South America, the carbon benefit of forest conservation is average per-hectare carbon content of above and below ground live biomass in each unit. We use 1km^2 resolution data from Saatchi et. al (2011). Units are tons per hectare.

4. Biodiversity benefits (B^b)

We use a rarity weighted richness index (RWRI) to measure the biodiversity benefit of forest conservation (Williams et al. 1996; Abell et al. 2011). An RWRI is a weighted count of all threatened species in a specific location, where the weight for each species is *inversely* related to the total area of its range in a larger geographic unit such as a country. Hence, a RWRI gives species with a larger share of their total range in a specific location more weight than species with a smaller share of their range in this location. The advantage of using RWRI (instead of a simple count of endangered species in that location) to measure biodiversity benefits of forest conservation in a given location is that RWRI more accurately reflects the contribution to ensuring species' survival of conserving that particular location.

To calculate RWRI for a given unit, we first count the number of threatened species whose ranges intersect the unit using digitized species ranges for mammals, reptiles, and amphibians compiled by the International Union for the Conservation of Nature (IUCN 2013) and digitized species ranges for birds compiled by Birdlife International (Birdlife International 2012). Threated species include those that are endangered, vulnerable, and critical. Next, we assigned each threatened species whose range intersect the unit a weight equal to 1/**A** where **A** is the total area (in square kilometers) of the range of that species in some geographical area that is larger than the unit. For units in Mexico and South America, **A** is for the entire world. For Central America, FCTT users may choose between **A** for country where the unit is located or **A** for entire world. Finally, we sum weighted counts for each threatened species in the unit to obtain a RWRI for that unit.

5. Hydrological benefits (B^h)

We estimate hydrological benefits using WaterWorld, an off-the-shelf integrated land-use/hydrological model (Mulligan 2013). We use the model to simulate the effects of deforestation on hydrological services at the watershed-level (i.e., drainage basin-level). We assume that these deforestation effects are directly related to the provision of forest hydrological services. That is, we assume that if the loss of forests in a watershed produces large changes in hydrological services, then those forests provide relatively high levels of hydrological services.

We use WaterWorld to generate two measures of the effect of deforestation on forest hydrological services: changes in water balance from a baseline scenario and changes water quality from a baseline scenario. Water balance is simply the difference between transpiration and precipitation and is measured in millimeters per year. The change in water balance proxies for the change in ground water as well as the change in surface water since aquifer recharge depends critically on water balance. Deforestation generally increases water balance because it reduces transpiration. However, since both positive and negative changes in water balance are disruptive—positive changes lead to flooding and negative changes lead to water shortages—we use as our measure the absolute value of the change in water balance.

Water quality is measured as the mean percentage of water polluted when forest is cleared for agriculture. Changes in water pollution due to deforestation are generally positive—that is deforestation leads to more pollution—but in some cases are negative. Therefore, some watersheds may be assigned a negative water quality benefit. We combine the water balance and water quality measures by normalizing each indicator by its median within the study area and then averaging the two. For one dataset, (subdataset 32 of the 1km South America data) we used mean rather than median values of water balance and water quality, because the median change there was zero (this dataset is market with an asterisk in the FCTT).

6. <u>Opportunity cost (C)</u>

For Mexico, we estimate the cost of forest conservation as the average per-hectare opportunity cost due to forgone agricultural revenues in each unit. We directly estimate opportunity costs only for ejidos and communidades, and then interpolate these costs for other types of units (such as private property) using a distance weighted average. We expect our direct estimates to be much more reliable than our indirect ones because agriculture is less likely to be the dominant land use on non-ejido and non-communidad land.

We consider two types of gross agricultural revenue: crops and animal products requiring pasture-land. For crops, we use a combination of data at different levels to estimate gross revenues. We use municipio-level crop-specific data on prices and yields, and unit-level crop-specific data on area planted in crops to obtain a per-hectare value of crops. The municipio-level data are from Servicio de Información Agroalimentaria y Pesquera (SIAP) and are averaged over the years 2009-2011 (SAGARPA 2011a). We do not adjust to inflation between 2009 and 2011.

The unit level data are from the Programa de Apoyos Directos al Campo (PROCAMPO), which requires land managers to report hectares planted in hundreds of crops each year (SAGARPA 2011b). To our knowledge, these are the only publicly available unit-level data on hectares planted in crops. We use 2011 PROCAMPO data. Note that we do *not* use data on PROCAMPO payments, only data on hectares planted.

For pasture-based animal products, we use municipio-level SIAP data on total revenues from cattle and sheep products, and divide by the number of hectares of pasture in the muncipio to get a per-hectare measure. We use a 2000 INEGI land cover map to estimate hectares in pasture (Velazquez et al. 2002).

For a given ejido/communidad, we then compute a weighted average of the per-hectare crop gross revenue and the per-hectare pasture gross revenue, where the weights reflect the relative split of land between cropland and induced pasture. For example, if an ejido/communidad had 160 hectares of cropland and 40 hectares of induced pasture, we used weights of 80% and 20%, respectively.

For Central America, the D.R. and South America, we also estimate the cost of forest conservation as the average per-hectare opportunity cost due to forgone agricultural revenues in each unit. Here, our estimates of agricultural revenues are from Naidoo and Iwamura's (2007) a 5 min grid (9 km2) data set.

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Appendix: South America 1km^2 Subdatasets

Number	Subdataset name	Geographic scope
1	Ecuador	Entire country
2	Bolivia-Santa Cruz	Santa Cruz department
3	Bolivia-El Beni, La Paz	El Beni and La Paz departments
4	Bolivia-Others	All remaining departments
5	Colombia-A	Departments Amazonas to Chocó
6	Colombia-B	Departments Córdoba to Tolima
7	Colombia-C	Remaining departments
8	Brazil-A	States Acre, Alagoas, Amapá , Distrito Federal, Espírito Santo, Paraíba and Rio de Janeiro
9	Brazil-B	States Goiás and Pernambuco
10	Brazil-C	States Ceará and Maranhão
11	Brazil-D	States Mato Grosso do Sul, Sergipe, and Rio Grande do Norte
12	Brazil-E	States Paraná and Piauí
13	Brazil-F	States Rio Grande do Sul and Santa Catarina
14	Brazil-G	States of Rondônia and Roraima
15	Brazil-H(São Paulo)	States of São Paulo
16	Brazil-I	State of Tocantins and municipalities of Barcelos and Jutaí in the state of Amazonas
17	Brazil-J	States of Bahia and Minais Gerais: municipalities with names beginning with A through H
18	Brazil-K	States of Bahia and Minais Gerais: municipalities with names beginning with I through Q
19	Brazil-L	States of Bahia and Minais Gerais: municipalities with names beginning with R through Z
20	Brazil-M(Mato Grosso I)	State of Mato Grosso: municipalities with names beginning with A through L
21	Brazil-N(Mato Grosso II)	State of Mato Grosso: municipalities with names beginning with M through Z
22	Brazil-O(Pará I)	State of Pará : municipalities with names beginning with A through G

23	Brazil-P(Pará II)	State of Pará : municipalities with names beginning with H through O
24	Brazil-Q(Pará III)	State of Pará : municipalities with names beginning with P through Z
25	Brazil-R(Amazonas I)	State of Amazonas : municipalities with names beginning with A through G, excluding Barcelos (see number 16)
26	Brazil-S(Amazonas II)	State of Amazonas : municipalities with names beginning with H through N, excluding Jutaí (see number 16)
27	Brazil-T(Amazonas III)	State of Amazonas : municipalities with names beginning with O through Z
28	Guyana and Uruguay	Whole countries
29	Paraguay	Whole country
30	Venezuela-Amazonas, Anzoátegui, and Bolívar	States of Amazonas, Anzoátegui, and Bolívar
31	Venezuela-Others	Remaining states
32	Chile-A	Regions Aisén to Bío, excluding Atacama
33	Suriname & Chile-B	Country of Suriname and regions Los Lagos, Los Ríos, Coquimbo and Atacama of Chile
34	Chile-C	Remaining regions of Chile
35	Peru-A	Provinces with names beginning with A through J
36	Peru-B	Provinces with names beginning with L
37	Peru-C	Provinces with names beginning with M through Z
38	Argentina-A(Buenos Aires)	Buenos Aires province
39	Argentina-B	Provinces Chubut, Capital Federal (city of Buenos Aires), and Jujuy
40	Argentina-C	Provinces Catamarca, Chaco, Corrientes, and Entre Ríos
41	Argentina-D	Provinces Córdoba, Formosa, and Neuquén
42	Argentina-E	Provinces La Pampa, Mendoza, and Misiones
43	Argentina-F	Provinces La Rioja and Río Negro
44	Argentina-G	Provinces Salta, San Juan, San Luis, and Tierra del Fuego
45	Argentina-H	Provinces Santa Fe, Santiago del Estero, Tucumán, and Lago Argentino department of Santa Cruz
46	Argentina-I	Remainder of province of Santa Cruz (no Lago Argentino)