MAPPING AND MONITORING OF ECOSYSTEM SERVICES IN CENTRAL VERACRUZ, MEXICO, TO STRENGTHEN PAYMENTS FOR ECOSYSTEM SERVICES AND PROMOTE INTEGRATED WATERSHEDS MANAGEMENT.

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Background

Mexico in general and, Veracruz state in particular, has been actively developing Payments for Hydrological Services (PHS) programs in response to marked environmental deterioration and concomitant socioeconomic impacts. The growth of these programs has created an interesting laboratory for their evaluation. The issue of targeting of PHS to maximize the impacts of these programs is being actively debated in the literature. The overall effect of PHS programs in Mexico on ecosystem service provision may be limited by a lack of guidance as to where payments should be made within watersheds in previously determined eligible areas. Other factors contributing to poor targeting include the lack of monitoring of actual ecosystem service provision and establishment of baselines needed to periodically evaluate program effectiveness. In order to provide scientific information to support decision-making and strengthen the PHS in central Veracruz, this project sought to identify priority areas providing multiple ecosystem services using four modules of the InVEST software including water yield, carbon storage, sediment retention, and water purification. Another objective was to establish long-term monitoring to evaluate the predictions of InVEST models that are often parameterized with static data from the literature organized into look-up tables. Furthermore, since the rapid transformation of natural ecosystems in the central part of Veracruz state means that the provision of ecosystem services will increasingly depend on the secondary vegetation and agroforestry systems, such as shade coffee plantations, another goal of this project was to assess the importance of shade coffee farms in priority areas that provide multiple ecosystem services. Finally, this project also sought to provide feedback to decision makers running PES programs in the region on the effects of their public policy, both in the context of future changes in land use, and in developed climate change scenarios in the state. This effort should improve the design of public policies focused on natural resources conservation and integrated watershed management in the study region. Once regional Tier 1 InVEST models were run with existing data from the literature, field monitoring was performed over a 14-month period within replicate (3) microwatersheds dominated by the five most common land uses in the region

(N=15; primary and secondary forests, shade coffee, cattle pastures and sugar cane). Equipment was installed for monitoring local climate, surface flows, water infiltration rates, and water quality during low and peak flow conditions. In addition, forest inventories were performed and soil cores and tree rings collected for the assessment of carbon storage. A number of datasets were generated from this work including data from weather stations, monthly stream flow measurements, stream height, sample collection during peak flow events, forest inventories, growth rings measurement, infiltration rates, laboratory assays for water and soil samples. The secondary data that was used included that obtained from previously published studies, publically available GIS layers, and databases from nearby weather stations.

Mapping and monitoring of ecosystem services

Current global deterioration and degradation of natural resources includes ecosystems that provide multiple benefits to society (MEA, 2005). The degradation and over-exploitation of ecosystems is of increasing concern to decision makers, particularly in understanding how ecosystems provide key services, how they response to disturbances, and the identification of critical areas for ecosystem service provision (Remme *et al*., 2014). For this reason, the concept of ecosystem services (ES) has been incorporated decision making and public policies focused on promoting best practices on natural resources management. Such policy instruments typically seek to eliminate the positive externalities that contribute to the deterioration of ecosystems and the services they provide by creating economic incentives to land owners for forest protection or restoration (Daily, 1997; Bryan *et al*., 2010). Programs proving payments for ecosystem services (PES) are one such instrument and are rapidly evolving and consolidating their role as useful mechanisms to ensure the provision of ecosystem services. PES programs seek to establish a links between the interests of the owners of ecosystems providing key services and the users of these services (Wunder, 2007) through voluntary contracts that award economic compensations for the conservation or restoration of these ecosystems.

Since 2003 Mexico has been operating the National Program of Payment for Hydrological Services. This program promotes the protection of priority basins by providing financial compensation derived from fees charged for federal water concessions. Currently, the program pays for two main services. The first is the payment for hydrological services, focused mainly on forest conservation to promote groundwater recharge and prevent soil erosion. The second modality consists of paying for the service of biodiversity conservation, and thus promotes the conservation of flora and fauna including up until recently agroforestry systems such as shade coffee. In 2008 an additional fund was established to promote local PES programs through matching funds. A Biodiversity Endowment Fund was also established in 2010 and supports the conservation of forested land in areas with significant biodiversity but that are not included in any other conservation areas including parks (SEMARNAT-CONAFOR, 2013). In the state of Veracruz many of these programs are currently operating, with a particular focus on hydrological services and the participation of municipal, state and federal authorities. These programs include the local matching programs FIDECOAGUA, COCUPIX, and FAPO, promoted by the municipalities of Coatepec, Xalapa and Boca del Rio respectively; the National PES Program promoted by the National Environmental Forestry Commission (CONAFOR); and the Environmental Fund of Veracruz (FAV), promoted by the Ministry of Environment of Veracruz. The watersheds of the La Antigua and Jamapa rivers are a central focus of these programs due to their economic importance and level of degradation (Maass et al., 2005; Muñoz-Piña et al., 2008).

While the state of Veracruz occupies only 3.6% of Mexico it is ranked third in biodiversity in the country and its rivers carry 33% of the countries surface flow. In contrast, Veracruz also ranks first in loss of natural vegetation rate at the national level due to strong focus on agricultural production including > 45% coverage by cattle pastures. All told only 18% of natural vegetation cover remains in the state, resulting in the loss of important ecosystem services. Over 40% of the state remains affected by high rates of soil. In addition, Veracruz is the state with the greatest of threatened and endangered species and is being affected by worsening flood and drought cycles and ever more frequent and powerful storms. Currently, PHS programs monitor forest cover only through satellite imagery, as a mechanism to assess the effectiveness of payments to preserve vegetation cover. However, there are an increasing number of publications emphasizing the need for new mechanisms to monitor and understand the relationships between multiple ecosystem services in payment programs. New methods of monitoring are needed that can establish a baseline for long-term monitoring of these programs, to assess the impact that such payments have, and determine how such programs might be improved.

Understanding of ecological processes that give origin to ES, and the effects of land use change over their provision, through these functions monitoring, allows determining the spatial trends of such provision. By identifying these trends, we can help to design conservation strategies for the ecosystems that meet with such conditions against other types of land use. In the last years, static and dynamic modeling tools based on computational algorithms, have been increasingly used to understand the spatial distribution of ES and to prioritize conservation areas. Despite the usefulness of these models, the PHS programs, are not leveraging such resource to identify priority areas within the watersheds. Therefore, it is essential to determine where these services are most important, canalize the PES to areas where the impact of service provision is more significant, and maximize the use of economic resources for such programs. We selected carbon storage services, surface water yield, and nutrient and sediment retention, for their high importance in the region, and for being the main focus of PHS in the country to date. The role of these services over the past years in Mexico, has taken much notoriety, especially on climate's change research agenda, in addition, the literature for these services is relatively large, as they also are good markers to evaluate the effects on land use conversion.

Goals and Objectives

This project sought to make use of the spatial modeling tool InVEST to map the provision of four ecosystem services (carbon storage, water yield, nutrient and sediment retention) and identify priority areas for their conservation. As described in previous reports, a monitoring network was established for all the variables associated with the production of these services in replicate microwatersheds dominated by different land uses, in order to evaluate the results generated by the models, and explore possible changes in service provision in the future due to land use and climate change.

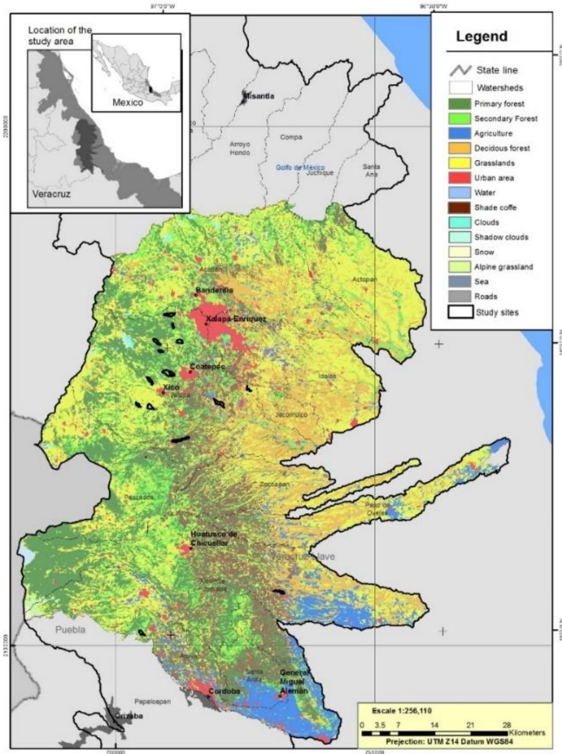
The specific objectives of this project were:

- Provide scientific evidence to evaluate and strengthen the PSE programs that are currently active in the region, and to promote the inclusion of shade coffee plantations in these programs.
- Identify priority areas that provide multiple ecosystem services in a coffee dominated landscape.
- Evaluate the impact of different land uses on the spatial pattern and magnitude of services provision.
- Finally, to understand how spatial patterns in the provision of these services would be affected under scenarios of change (climate change, land use change).

These objectives helped us to establish of a long term monitoring program of ecosystem services, the evaluation of service provision in microwatersheds dominated by different land uses using field data and stimulate improvements in public policies designed to restore or conserve such services. Here, we provide a brief description of fieldwork, however, for complete details on data and analyses pleas direct questions to Robert Manson (robert.manson@inecol.mx), Pierre Mokondoko (sumpark182@gmail.com), or Lorelí Carranza (lorelicj@gmail.com). Also, InVEST models are described in more detail in Tallis et al., (2010).

We selected 15 microwatersheds to monitor indicators of the aforementioned environmental services (Figs 1 and 2). Process was mainly based on a set of primary and secondary criteria. The primary criteria used were: (1) microwatersheds with first order streams with perennial flows; (2) where the dominance of particular land uses and land cover was greater than 60% (typically ≥ 70%); (3) similar soil types (principally Andesols); (4) and finally within an altitudinal range of 700-1,700 above sea level (MASL) to minimize dramatic changes in climate in general and rainfall in particular. After making an initial selection of microwatersheds with these criteria, we made a second cut based on secondary criteria including: (5) the logistical concern of having the sampling points for microwatersheds located < 1 km from the nearest road; (6) a somewhat standardized range of microwatershed size (> 10 ha < 150 ha) to minimize changes in hydrological responses due to drainage area alone; and finally (7) all sites selected had to be largely free of point sources of pollution and somewhat secure for leaving stream gauges, and with a high level of interest by the land owner.

a)



b)

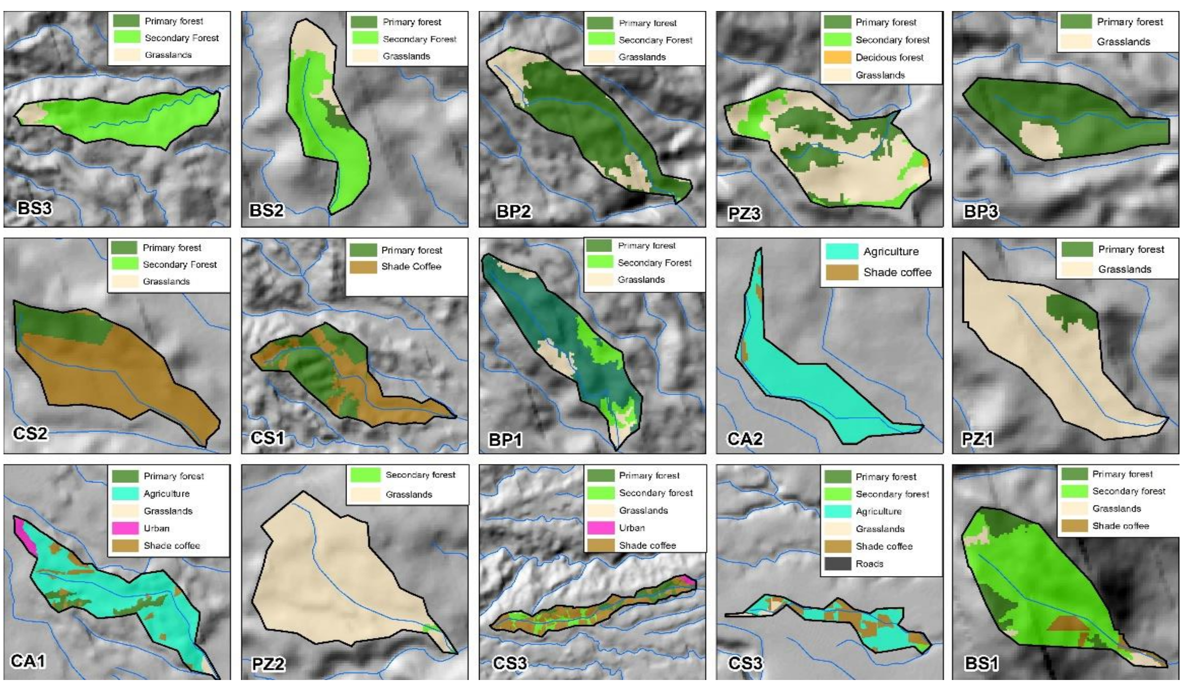


Figure 1. a) Map of land use, land cover and the study microwatersheds (n=15) in upper regions of the Antigua and Jamapa watersheds in central Veracruz. Also shown are the subwatersheds were ecosystem service provision is being mapped (black) and the limits between the states of Puebla and Veracruz (grey). b) Dominant land uses within microwatersheds.

Currently, seven weather stations were installed collecting data at 30 minute intervals for the following variables and indexes:

Table 1. Description of the 28 variables for which data was collected by the seven weather stations installed near the study watersheds of this project

Simbology	Description	Simbology	Description
Temp Out	Outside Temperature	*Rain*	Rainfall
Out Hum	Outside Humidity	*Rain Rate*	Rate of Rainfall
Dew Pt.	Outside Dew Point	*Solar Rad.*	Solar Radiation
Wind Speed	Wind Speed	*Solar Energy*	Solar Energy
Wind Dir	Wind Direction	*Hi Solar Rad.*	High Solar Radiation
Wind Run	Wind Run	*UV Index*	UV Index
Hi Speed	High Speed	*UV Dose*	UV Dose
Wind Chill	Wind Chill	*Hi UV*	High UV Index
Heat Index	Outside Heat Index	*Heat D-D*	Heating Degree Days
THW Index	Temp/Hum/Wind Index	*Cool D-D*	Cooling Degree Days
THSW Index	Temp/HUM/Sun/Wind Index	*In Temp*	Inside Temperature
Bar	Barometric Pressure	*In Hum*	Inside Humidity
In Dew	Inside Dew Point	*In EMC*	Inside Equilibrium Moisture Content
In Heat	Inside Heat Index	*ET*	Evapotranspiration

Figure 2. Davis Vantage Pro2^{TM} Plus (UV and Solar Radiation Sensors) installed in the communities of "Ixhuacan de los Reyes" and "Pocitos".

We chose a set of ecological functions as biophysical indicators that are directly associated with the quantification of ES, relatively easy to measure, are key variables to InVEST models, and of interest for local PHS schemes. The evaluated indicators include:

Water yield: we obtained data from weather stations network from the study region including those of the NSF project, INIFAP, SMN, CONAGUA and those installed for this project. Uninterrupted measurements of normal base-flow and peak flow (rain events) from streams were taken continuously for a period of 14 months. Additionally, we installed 15 Solint Level logger divers in the water column or the stream level during both rain events and base flow periods. All divers were installed at the output of every catchment to monitor the stream heights continuously. To estimate hydraulic conductivity, we measured unsaturated infiltration in the field using portable pressure and constant-load infiltrometers INDI-INECOL (Gómez-Taggle *et al*., 2011). Six infiltration assay were performed at each selected side, using four different tensions. Also, soil samples were collected and analyzed in the laboratory of Soils at INECOL for physical and hydrological soil properties.

Figure 3. Photographs of the hydrological monitoring conducted in the study microwatersheds including: a) weather stations, b) tower to collect samples of suspended solids and nutrients during peak flow events, c) monthly measurement of stream flow volume during flow periods using a flow meter, d) infiltration rate measurement on each land use.

Nutrient and sediment retention: during the storm events (10 peak flows) and base-flow monitoring, water samples were collected and processed at the laboratory of Soils in INECOL (NO_3, PO_4-P and SST). Nutrients were determined exclusively for pasture and shade coffee-dominated watersheds. During peak flows we used towers with auto sealable bottles to collect water samples for SST. Also, soil samples were collected for determining physical characteristics, using Stainless steel borers.

Carbon storage: We made numerous field trips to perform a forest inventory survey of those watersheds with considerable canopy coverage including: primary forest, secondary forest and shade coffee. This monitoring was based on the methodology established by the National Forestry Commission (CONAFOR), in the national forest and soil inventory (INFyS) resampling handbook (2011). For each one of the sampling units (4 by microwatershed), all trees inside them were counted, identified and numbered starting from the center outwards, with an initial orientation to the north of the cluster and proceeding clockwise. Dasymetric information was gathered for those trees with a DBH greater than 7.5 cm; the DBH (Diameter at breast height) measured at 130 cm from the ground. For the trees that meet this condition, the following information was documented: genus, species, basal diameter, condition (alive, dead and standing, or stump), total height, crown diameter, crown height, crown shape and commercial height (only trunk height). Samples of a tree ring were analyzed to determine growth rates and carbon accumulation curves for dominant tree species present in each study microwatershed. Furthermore, we counted with a broad set of hemispheric photographs to analyze the cover and LAI.

Identifying priority areas

Using publically available data and literature reviews we obtained initial maps for the provision of services in central Veracruz using the Tier 1 models of InVEST. In general, the study region showed a heterogeneous behavior due to multiple interactions between different landscape variables and services. Nevertheless, since in Veracruz hydrological services in general, and more specifically the service of water provision, are the most relevant ecosystem service for decision makers we are concentrating efforts in the delineation of areas of hydrological service provision and evaluating how this compares to areas eligible or actually receiving PHS as a way to determine the success of targeting efforts in study watersheds. We combined the spatial information of services provision maps to identify the areas with greatest potential for more than one service. These areas were delimited with spatial analysis tools (overlap analysis, spatial correlation), and standardization of service provision range. Figure 4 presents the derived priority areas, or, in other words, the areas that are important for simultaneously providing the higher levels of provision for the selected ecosystem services. These areas also represent the areas that could be targeted by national and local PHS programs to help insure that they have a greater impact, maximizing the use of financial resources for conservation where PHS can provide more than one benefit. Overall we identified some 197,067 ha of priority areas for the provision of multiple ecosystem services.

These results were subsequently compared to areas that are eligible or actual have received PHS in the study region during the period 2003-2014 to determine the degree of effectiveness of the national PHS program in targeting key areas of service provision. A manuscript describing these results will be provided soon.

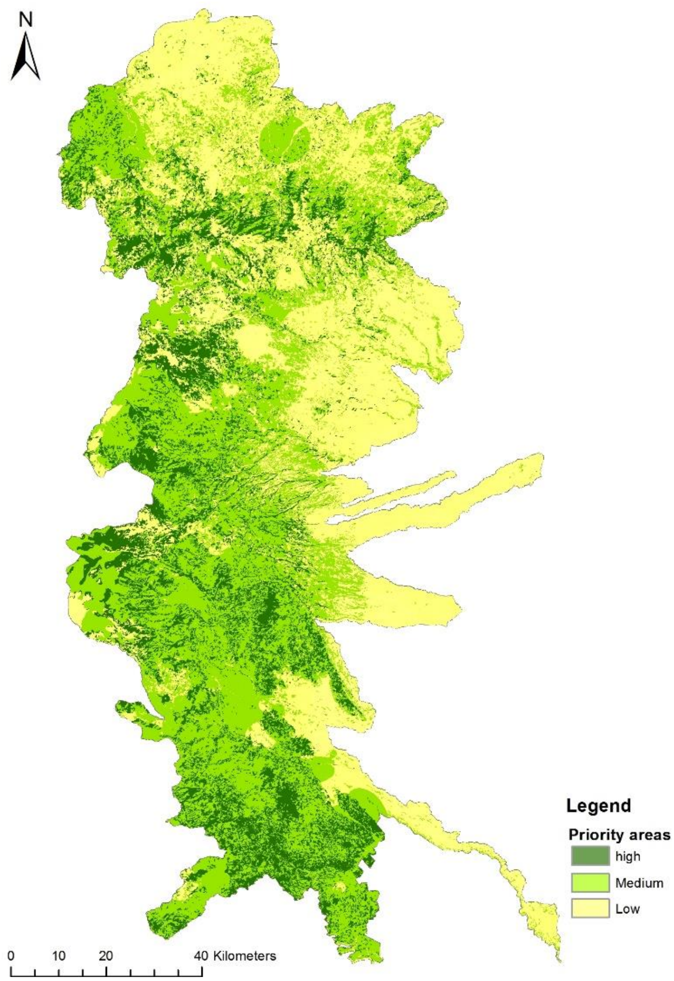


Figure 4. Distribution of priority areas in Central Veracruz for the provision of multiple ecosystem services including water yield, sediment retention, carbon storage and nutrient retention. Data obtained from Tier I InVEST models.

Other collaborator to this projects

Contributors	Contributions to the field work
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References

- APHA, A. WPCF. 1992. Métodos normalizados para el analisis de aguas potables y residuals (D. d. Santos Ed. 17 ed.)
- Balvanera, P., Pfisterer, A., Buchmann, N., He, J., Nakashizuka, T., Raffaelli, D. y Schmid, B. 2006. Quantifying the evidence for biodiversity effects on ecosystem functioning and services. *Ecology Letters*, (2006) 9: 1146–1156.
- Beramendi-Orosco, L., Gonzalez-Hernandez, G., Villanueva-Díaz, J., Santos-Arevalo, F., Gómez-Martinez, I., Cienfuegos-Alvarado, E., Morales-Puente, P and Urrutia-Fucuguachi, J. Modern radiocarbon levels for northwestern Mexico derives from tree rings: a comparision with northern hemisphere zones 2 and 3 curves. RADIOCARBON, 52: 907-914.
- Brown, S., Gillespie, A., and Lugo, A. 1997. Biomass estimation methods for tropical forests with applications to forest inventory data. *Forest Science*. 35(4), 881-902.
- Camargo-Hernández, J. and Franco, V. Procesos de Erosión-Sedimentación en cauces y cuencas. Programa Hidrologico Internacional de la UNESCO para America Latina y el Caribe (Vol. 22). Uruguay: UNESCO.
- Chamizo, E., López-Gutiérrez, J., Ruiz-Gómez, A., Santos, F., García-León, C. and Alfimoz, V. 2008. Status of the compact 1 MV AMS facility at the Centro National de Aceleradores (Spain). Nuclear instrument and Methods in Physics Research B 266(10): 2217-20.
- Diez-Herrero, A., Moya, J., Corominas, J., Bodoque, J. M., Muntán, E., Gutiérrez, E. and Ballesteros, J. A. (2007). Dendrogeomorphological studies for natural hazards research in the Iberian Peninsula (Spain and Andorra). *In Geophysical Research Abstracts* (Vol. 9, p. 07036).
- Eigenbrod, F., Armsworth, P.R., Anderson, B.J., Heinemeyer, A., Gillings, S., Roy, D.B., Thomas, C.D., Gaston, K.J., 2010. The impact of proxy-based methods on mapping the distribution of ecosystem services. *Journal of Applied Ecology* 47, 377–385.
- Geissert, D., Dubrecq, D., Campos, A., y Meza, E. 1994. Carta de paisajes geomorfoedafológicos de la región volcánica Cofre de Perote, Estado de Veracruz, México. Escala 1:75,000 (México: Instituto de Ecología, AC. ORSTOM-CONACYT)
- Gómez-Tagle A. and Geissert, D. Manual de infiltración: Infiltrómetro de tensión INDI-INECOL 2009: Instituto de Ecología AC. Xalapa, Veracruz.

- Layke C (2009) Measuring Nature's Benefits: A preliminary Roadmap for improving ecosystem service indicators. WRI Working paper. *World Resource Institute*, Washington DC. http://www.wri.org/project/ecosystem-service-indicators.
- Locatelli, B and Leonard, S. 2001. Un método para medir carbono almacenado en los bosques de Malleco (Chile). *Bois et Forest des Tropic*. 276(1), 69-80.
- Meza, E and Geissert, D. 2007. El comportamiento hidrodinámico de Andosoles con uso diferencial en el municipio de Coatepec, Estado de Veracruz, México. En Reporte técnico final del proyecto No. INE/A1-064/2007. Instituto de Ecología, AC.
- Muñoz-Villers, L. E., 2008. Efecto del cambio en el uso de suelo sobre la dinámica hidrológica y calidad de agua en el trópico húmedo del centro de Veracruz, México. Tesis de Doctorado. Universidad Autónoma Metropolitana. México, D.F.
- Muñoz-Villers, L., and McDonnell, J. 2013. Land use change effects on runoff generation in a humid tropical montane cloud forest region. *Hydrology and Earth System Sciences*, 17(9): 3543-3560. doi: 10.5194/hess-17-3543-2013.