I. Introduction: Context and Significance

1. Context

The Purús River might be considered one of Amazonia's "lost rivers." It is one of the longest tributaries of the Amazon, almost 3000 km, of which about the last 500km are in Peru. The Upper Purús has been described as one of the most remote places on the planet, and among Amazonian habitats, one of the least affected by people. It is considered among the most biodiverse regions of South America and a place that still harbors "stone age" tribes according to WWF assessments. This perception of a place at the ends of the earth and the beginnings of time has resulted in the creation of the 2,724,000 ha bi-national Purús-Chandless Park, which is the size of Costa Rica and one of the very largest conservation areas in tropical America. Peru has the third largest area of tropical rainforests in the world, and compared with other areas in the Western Amazon, like Brazil and Bolivia, the rates of Peruvian forest conversion have been relatively low and in fact are declining in spite of significant migration into the lowlands to hubs like Pucallpa and Puerto Maldonado (Arce-Nazario 2007; Oliveira et al. 2007). But this trend could change dramatically.

Upper Purús forests, among the least researched in all of Amazonia, could well be affected by the ambitious program of infrastructure development and basin-wide economic integration associated with the Inter-Oceanic Highway proposed by IIRSA (Initiative for Integration of Regional Infrastructure in South America). This project will connect western Brazil, lowland Peru and Bolivia with Pacific ports and ultimately Asian markets. In November 2008 the Regional Government of Ucayali approved the building of a paved highway connecting Puerto Esperanza, the provincial capital of Purús, to Madre de Dios and to the Inter-Oceanic Highway. The Upper Purús, although largely under formal protection, lies in the path of this "progress" and most observers expect the region to reproduce the "usual" trajectory described in much of the literature on Amazonian development: the classic clash between "wild nature" and "feral capitalism" producing ephemeral construction and speculative booms, short- term economic flurries, and long-term ecological degradation, as forests are cleared, soils lose their fertility, migrants come, go, and leave desolation and environmental catastrophe in their wake (Fearnside 2005; Killeen 2007; Laurance et al. 2004; Malhi et al. 2008; Rodrigues et al. 2009).

But is this model actually accurate for this region? Is it realistic for this place in this time? Our preliminary field research, as well as long experience on Amazonian frontiers, makes us suspect that the upper Purús might be an exception to the "usual," or prove a harbinger of different processes. If we can understand why the region might not conform to the "typical trajectory" of an agrarian frontier that confronts forest landscapes and their economies by simply clearing them, it may provide insight into emerging "frontier" dynamics. The astonishing decline by 70% in deforestation rates in Brazil over the last year suggests that there may be broader structural changes afoot.

Regional in-migration into the Upper Purús is overwhelmingly urban, in contrast to the historical dynamics of the Brazilian TransAmazon, BR 364, and BR 163, regions that developed around new roads and that more or less have come to define problematic Amazonian developments. Our site differs from these iconic frontiers in that it has a globally integrated economy that so far functions on endogenous transport systems called *varaderos* (forest roads developed largely in earlier periods of settlement including Pre-Columbian, and the Rubber Boom), as well as other more recent small-scale "informal roads" (*trochas* and *caminos*). These *varaderos* are common throughout Amazonia, and indeed Wallace described one some 10 meters across and 20 kms long that connected the Upper Rio Negro with the Orinoco and was regularly maintained by Indians (Wallace 1889). By comparing the forest economies whose resources and institutions largely reflect past histories and endogenous infrastructure, with the returns to the agrarian economies that typically confront woodland economies by deforesting them, we may be able to elucidate some new frontier processes and strategies. This study has many implications for reassessing regional histories, "wild" ecologies, development policies, and the impact of different forms of regional infrastructure in this ecologically significant part of the Amazon basin.

Our multi-disciplinary study emphasizes complex dynamics to understand the "clash" of forest versus agrarian "civilizations" in the development of the Upper Purús. We suggest that *varaderos* have a

distinct, anthropogenic vegetation that developed historically as sites of resource development (Brazil nut, latexes, cacao, mahogany for example) and food trees that supported travelers, especially around *puestos* or camp sites. Such manipulation along trails and camp sites is documented for indigenous groups and modern extractors (Alexiades 2009; Posey & Balée 1989; Rival 2006; Rival 2002; Schroth et al. 2004; Wolters 1999). This vegetation serves both non-timber forest production needs and supports trade. It also supports various forms of clandestine trade by rendering it invisible to the usual monitoring techniques. The structure of the anthropogenic "*varadero* vegetation" we suggest, will have a different complex of species compared to non-*varadero* vegetation, and will also differ from that of the modern *trochas* (logging routes) in ecosystem structure and impacts. Road ecology has become a major research topic in tropical forest fragmentation studies, but the possibility of non-catastrophic transport-based ecologies is largely unexplored in the modern context (but see (Angelson 2007).

2. Goals and Hypotheses

In this project we have three general research goals:

A. First, we will ascertain the extent and impact of endogenous infrastructure on regional vegetation in terms of structure and age. ***We hypothesize that endogenous infrastructure (including varaderos, trochas and caminos) has significant effects on the adjacent forest vegetation. This anthropogenic vegetation differs in structure and species from sites not immediately affected by such infrastructure and may have greater carbon uptake and sequestering capacities than other types of forests*** (Greene 2006; Hill & Santos-Granero 2002; Peru. Ministerio de Relaciones Exteriores. 1903; Santos-Granero 2002; Santos-Granero & Barclay 2000; Vidal 2000). This research involves historical analysis, high resolution remote sensing integrated with field measurements of forest structure, and ecological studies.

B. Second, we hypothesize that the modern, globalized regional political economies operating in the Upper Purús are linked in complex ways to the forests as direct sources of goods and employment or indirect benefits and rent. We will carry out comparative economic evaluation of the forest-dependent economies of the Upper Purús (timber, coca trade, non-timber forest products), and conservation economies (park management and REDD) with local agriculture and cattle-raising, using formal data as well as interviews to derive their returns and impacts. This research also includes ethnographic techniques involving institutional mapping including tenure and access regimes to resources and land, and political and economic strategies of relevant social movements (environmental, indigenous, business, logging, coca trade) as they relate to natural resources, to construct an analysis of the regional economy and its dynamics.

C. Third, we hypothesize that the local range of forest-based economies including non-timber forest products, the clandestine economies of timber and the coca trade, as well as the "conservation economies" are economically and politically powerful enough (and now institutionally stable enough) to resist the deforestation pressures that have been characteristic of Amazonian frontiers. The institutions and the forms of governance associated with these economies further re-enforce forest systems. We expect that the "clearing for claiming," land speculation, subsistence farming, and low-value ranching will neither generate production or rent returns great enough, nor are they politically powerful enough to drive a threshold shift in the existing forest dependent economies. We will investigate these issues through the comparative research on economies described above, study of historical and contemporary documents, and extended interviews with a range of individuals involved in Upper Purús business, administration and politics.

This research has broader relevance for analysis of forest economies, "informal" transport routes and alternative development trajectories. If our third hypothesis should prove incorrect, our research would provide insight on how and why powerful economic entities succumbed to an agrarian frontier, a question of considerable interest. All the systems under consideration, whether forest or agrarian, have significant "instability factors" (resource depletion, markets, illegality, institutional continuity) and although this is not the focus our study, our research can provide insights into the limits of sustainability and resilience of such systems under development pressures.

3. Significance

This research adds to an emerging literature on anthropogenic forests, roads, regional integration, Amazonian history, deforestation and development in several novel ways: 1) It explores the historical ecology of *travel* in creating forests that now both supply local economies as well as supporting high value long distance trade and so contributes to the literature on Amazonian anthropogenic forests; 2) It develops an analysis of endogenous and historical infrastructure lacking in other research on "unofficial" roads in Amazonia; 3) It links this infrastructure history to vegetation types, and to a "constructed nature" that involves use values and commercial forest products, but also includes other functions of forests including possible environmental rents and clandestine economies; 4) It analyzes the economies and institutional setups that use, benefit from and control endogenous infrastructures; 5) It compares the economies, policies, institutional structures such as property and access regimes, and political actors (social movements, environmental organizations, the Catholic church, the army, local governments, illegal syndicates, traders) in the shaping of land uses in response to the pressures of an agrarian frontier; 6) It provides socio-environmental baseline data for changes that could attend road development; (in case our third hypothesis proves incorrect we will have information on the institutions, governance, local economies and many types of forest structure); 7) It could provide alternative approaches to infrastructure development in the same way that the study of indigenous production systems provided principles and techniques to inform and enhance the sustainability of contemporary tropical agriculture. We view this research as a rethinking of Amazonian frontiers in a context of local historical ecologies, infrastructures and substantive structural change in regional economies and in the way these now interact with global discourses and demand. In light of global warming and biodiversity erosion, a well-functioning anthropogenic landscape can serve as a useful matrix for regional conservation efforts, and as a springboard for understanding both ecological resilience and sustainability.

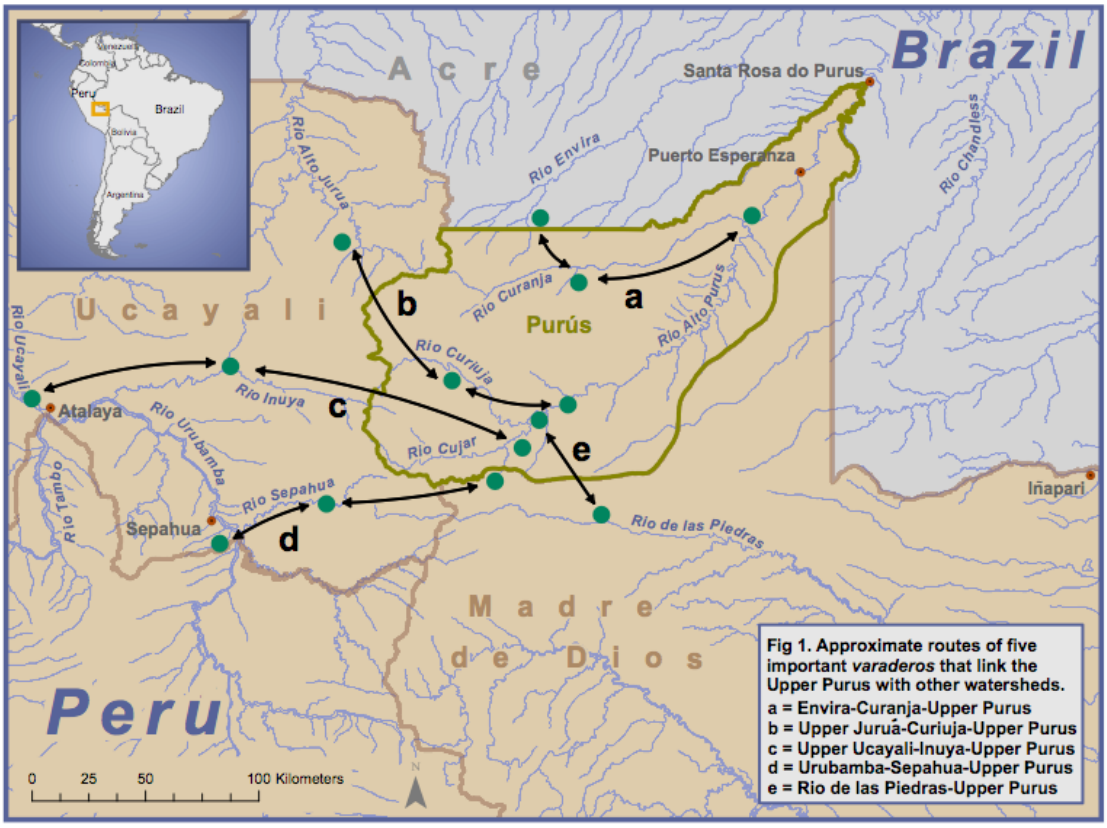
II. State of Knowledge

1. Brief History of Purús infrastructure: *Varaderos*

The upper Amazon, embracing a host of watersheds including the Madre de Dios, Ucayali and Upper Purús, has at least a 6000 year history of human occupation (Bush et al. 1989; Bush et al. 2007a). The Purús Basin as a whole shows evidence of complex settlements and engineering with widespread geoglyphs (more than 250) and anthropogenic soils (Korpisaari 2003; Lima et al. 2002; Schaan et al. 2008). The region has a long history of Inca migration as well as interaction with Andean economies (Santos-Granero 2002). It also has a surprisingly complex, well- documented, relatively recent history: during the late 19th century, the upper Purús was a site of several colonial wars. As the most economically dynamic part of the Amazon in the late 19th and early 20th centuries, there was a great deal of interest in this region by international colonial powers (Britain, the US, Belgium) as well as hemispheric aspirants (Peru, Brazil, Bolivia), with many survey expeditions with very specific directives about locating endogenous "jungle roads" for both military and economic reasons (Hecht 2010). Indeed, Peru's governmental agency of the "Vias Fluviales" in the early 1900s devoted numerous expeditions to exploration of endogenous infrastructure. The marching orders for the Mixed Reconnaissance Commission (carried out jointly by Peru and Brazil) involved locating and mapping *varaderos* (Da Cunha 1905). Travelers, from the most scientific to the most casual, commented on these linkages between watersheds, portages and economies (Chandless 1866; Da Cunha 1905; Domínguez & Gómez 1990; Pearson 1911; Reis 1953; Soria Casaverde 2008; Woodroffe 1914). Many of these roadways were named and described by travelers, and astonishingly enough, are still widely used today, according to our preliminary field research.

The Upper Purús has been especially subject to "wild nature, primitive natives" narratives, so the impacts of historical militarization and especially of the rubber period which unfolded in this region from the 1860's to the 1920s have been largely overlooked. The Upper Purús was famous in the colonial and rubber periods for its rich resource base and had a filigree of sub-canopy transport routes connecting meanders, tributaries, settlements, as well as large watersheds (see Fig. 1). These *varaderos* were and are

also seasonally important when the water levels of the upper tributaries were so low that even canoes found navigation difficult. The vegetation around these *varaderos* were both sources of goods and provided "traveler support" especially at "resource nodes" trading posts, or *puestos* where travelers



stopped temporarily along the pathways (Greene 2006; Hill & Santos-Granero 2002; Peru. Ministerio de Relaciones Exteriores. 1903; Santos-Granero 2002; Santos-Granero & Barclay 2000; Vidal 2000).

We know from studies of historical ecology that movement through landscapes -- not just settlement -- generated significant landscape changes, altering forests and producing resource "banks" of useful species that covered large areas (Anderson 1989; Balée 1994; Balée & Erickson 2006; Cormier 2006; Heckenberger et al. 2008; Posey & Balée 1989; Posey & Balick 2006; Rival 2002; Vidal 2000). For native peoples, travels historically involved ritual, raiding, warfare, hunting, and gathering treks, as well as movements of goods and commodities within and between regions. The rubber period further developed existing native infrastructure and expanded it as latex economies tied the most remote creeks of the upper Amazon through a system of portages, animal transport, and steamships to international ports and global markets. Modern economies use still use a surprising number of these systems but have also built informal roads locally known as *trochas*. Logging enterprises in the Upper Purús are almost entirely clandestine and often engage in both logging and processing within the forest. They commonly use local residents to haul blocks of wood -- often over considerable distances -- to rivers. The new roads are likely to have different impacts.

In the Purús, current property regimes, institutional structures and economic activities tend to support forests because they are residues and reinventions of socio-environmental systems based on woodlands, featuring food trees, tree resources like Brazil nut, cacao and mahogany and long-distance trade in a variety of other plant products (Allen 2005; Machado 2001; Rivera Cusicanqui 2003; Schultes 1981; Shohov & Lamazi 2004; Soux 1993; Wolters 1999). These commodities are based in institutional histories that were predicated on resource access regimes and territorial control (such as indigenous lands)

rather than agrarian property rights (Cotta et al. 2008; Dias et al. 2003; Kainer et al. 1998; Lachenaud & Sallee 1993; Shohov & Lamazi 2004; Wolters 1999; Zhang et al. 2006). This system of endogenous and informal infrastructure provides access to local resources and trading routes as well as larger-scale movement of people and goods and the landscape resources to support them. Since modern trade in the Upper Purús involves clandestine products as well as more traditional goods, regional elites and local people who benefit from the various types of commerce may find a standing forest especially useful as the "mantle of the poor" as well as the "invisibility cloak" for highly profitable clandestine activities.

The area is also important for the conservation economies that have fed significant funds into local and regional economies through projects for setting up and managing protected areas, both as sites of important biodiversity and as homelands of indigenous groups. Moreover, what appears to be an emerging economic possibility for carbon offsets and conservation "rents" (such as REDD) suggests another dimension in the regional development mix that could substantively affect forest "futures"(as in trading futures"). The potential for "no cost" returns on investment in forest acquisition for conservation offsets if access regimes are respected, versus the costs for deforestation for the usual speculation on pasture development, may also be affecting land use choices. Veiling clandestine trade (and perhaps benefiting from "tolls"), the returns to timber and non-timber forest products, and potential environmental rents may be a formidable bulwark to the standard speculative agrarian frontier that has dominated Amazon development.

2. Roads and Deforestation: Political ecologies of catastrophe

For many researchers, roads are the most important proximal cause of deforestation (Arima et al. 2005; Caldas et al. 2007; Fearnside 2002, 2007; Laurance et al. 2004; Leonel 1992; Mahar 2000; Perz et al. 2008; Pfaff et al. 2007). Analysis of post-clearing impacts have stimulated a sub-discipline of road ecology, and in Amazonia especially have been important studies of fragment ecology (Arima et al. 2005; Broadbent et al. 2008; Ferraz et al. 2003; Hawes et al. 2008; Laurance 2002; Laurance et al. 2006; Lees & Peres 2009; Stone et al. 2009). The understanding of the impact of roads in the Amazon is largely informed by the experiences of the eastern Amazon, the "arc of fire" on the Amazonian southern flank, especially Mato Grosso and southern Pará, places where much of the road infrastructure was built during and after the Authoritarian period (1964 -1985) where the social and environmental consequences of the construction or alternatives to it were largely ignored (Hecht & Cockburn 1989; Schmink & Wood 1992). The national and international outcry over land conflicts, violence, displacement, environmental destruction, fraud and corruption associated with clearing linked to construction of the TransAmazon and the BR 364 (Cuiabá-Porto Velho) created enormous political problems both within Brazil and internationally. The controversial events of the 1970s and 1980s related to highway building profoundly hampered official road construction in the next decades because of political and environmental concern over the impacts of deforestation, difficulty in convincing international lenders to finance roads in forests and local political volatility and violence (Alston et al. 1999; Araujo et al. 2009; Simmons 2004; Simmons et al. 2007). The financial trials of the late 1980s and 1990s further put a brake on large-scale road building throughout the Amazon. One result was the development of "unofficial roads"; in some areas of eastern Pará, some 80% of the roads were of this type according to satellite data (Lentini et al. 2005). In Peru, informal roads have been constructed but to a more modest extent (Maki et al. 2001). The early part of the this century, however, has seen a reanimation of large-scale continental projects now described as essential for global, rather than merely national integration.

The political ecology of unofficial roads, at least as this has been described in Brazil involves interactions between states, loggers and farmers (Perz et al. 2007a; Perz et al. 2007b). The needs of loggers and the livelihood desires of small farmers produce an occasionally conflictive, but relatively symbiotic interaction where access to remote areas for timber are then followed by agriculture or livestock. Monitoring or regulating such road building is difficult at the level of the state for contradictory reasons. Local decentralized *municipios* often lack the technology or the political will to control the logger/farmer economies and may depend on revenues, bribes, and votes from these constituencies. On soybean frontiers in Bolivia and Mato Grosso, the logging and small farm dynamic is not so much in

play, and for the most part the clearing dynamic involves direct conversion to agroindustrial production (especially the case in Bolivia), or shifts from large-scale pasture to soy (Fearnside 2007; Hecht 2005; Jepson 2006; Nepstad et al. 2006). The rise of democratization has also produced dynamic social movements which may be very much in favor of roads, even as indigenous and traditional populations may counter these activities. Thus roads as an element in the resource and development dynamic in Amazonia have become highly contested, especially when the frontier was seen as essentially an agrarian one. Roads are now an active site of reimagining forms of development that contrast with the historical processes of unfettered forest destruction (Lima et al. 2006; Moran 1983, 1993; Smith 1982).

There are, however, many places in Amazonia where forest economies have inhibited the extension of the agrarian frontier as in Acre, where informal road building in extractive reserves has followed *varaderos*, and in some Kilombo areas, such as Curiaú in Amapá. Further, in areas already inhabited for some time, the construction of roads does not by definition produce a deforestation dynamic (Angelson 2007). The central question then pertaining to Amazonian deforestation is whether powerful forest economies, which have their roots literally in the structures of the forest itself, can counter agrarian pressures for deforestation. Research on Peruvian road building shows, in general, a fairly feeble agrarian frontier (Maki et al. 2001; Santos-Granero & Barclay 1998), but offers limited explanations of why.

III. Plan of Work

1. Analytic Frameworks.

The approach we take to these questions is that of political ecology as well as historical ecology. Political ecology analyses are by definition heterodox in their methods using the tools of both the social and the natural sciences to develop a "thick description" of landscape and its politics. Political ecology unpacks the political economies and the power structures that shape the use of resources in terms of historical legacies and contemporary contexts and evaluates their bio-environmental effects. The biophysical focus reflects historical ecologies (and cultural ecologies) as well as modern environmental impacts. Amazonia has a distinguished history of such approaches and major impacts on thinking about tropical development. (Aldrich et al. 2006; Balée 1994; Balée & Erickson 2006; Bush et al. 2007b; Caldas et al. 2007; Cleary 2001; Coomes & Burt 2001; De Toledo & Bush 2007; Erickson 2006; Harrison 1999; Hecht 1985, 2005; Hecht & Cockburn 1989; Kainer et al. 2003; Perz & Skole 2003; Raffles 2002; Rudel et al. 2002; Santos-Granero & Barclay 2000; Schmink & Wood 1992; Simmons 2004; Vosti et al. 2003).

By analyzing the "powers and the interests" (and the impacts), political ecology has been especially influential as a critique of many forms of tropical development such as industrial agriculture, ranching and exclusionary conservation. The approach however has also been especially compelling for providing practical and policy guidelines that focus on the equity and sustainability of development trajectories. This group of PIs is especially able to efficiently employ this complex approach because of their deep familiarity with the region and its history, their interdisciplinary training and research records, and their influential roles in the development of political ecology as a "sub-discipline" in geography, anthropology and rural/resource sociology (Adams 2009; Adger et al. 2005; Alimonda 2002; Bradley & Millington 2008; Bryant & Bailey 1997; Ciccantell 1999; Hannigan 2006; Hayward 1998; Meyer 2001; Neumann 1998, 2005; Peet & Watts 2004; Peluso & Watts 2001; Turner & Robbins 2008; Zerner 2000; Zimmerer & Bassett 2003). We describe our methods in the next section.

2. Purús Analysis

Research Area: The Extent and Impacts of *Varaderos*

A. *Historical recovery of data on local infrastructure in the Upper Amazon*: In order to understand the extent and antiquity of local infrastructures, a review of historical travel, chronicle and ecclesiastic documents will be carried out, as well as an analysis of regional mapping exercises such as those from 1866 associated with the Treaty of Ayacucho and the flurry of mapping carried out in the 1890s-1900s during the "scramble" between Brazil, Bolivia and the Peru over the Purús which noted the location of *varaderos* and "ancient roads". More recent government surveys and Brazilian data such as Landsat that takes in some of these border areas will also be consulted. We will be eliciting oral histories and local

knowledge of this infrastructure from local people. This will be carried out in archives in Brazil and Lima, but excellent collections also exist at UCLA and Stanford. This information will be mapped and serve as an input to both the historical ecology and remote sensing components of the project.

B. Historical infrastructure and remote sensing.

The use of remote sensing technologies for tracking sub-canopy degradation and logging impacts in tropical forests is relatively well developed (Asner et al. 2002; Felton et al. 2006; Lentini et al. 2005). The use of high resolution (1-30 m) multi-spectral imagery can pick up a combination of gaps created by tree falls and the linear features of disturbance associated with logging (skid) trails (Asner et al. 2002: Wasseige and Defourney, 2004). We assume active sub-canopy roads, depending on their usage, have similar patterns of disturbance and geometric shapes as in logging disturbance. To test this hypothesis, we will use data from a variety of satellite imagery at different spatial resolutions such as Quickbird (0.6-2.4 m), IKONOS (1-4 m), ASTER (15 m), Landsat ETM (15-30 m), and radar data from Japanese ALOS satellite (10-20 m). Once the detectibility of individual or combined imagery for sub-canopy roads is determined, we will develop a multi-scale fusion and contextual classification approach to map the extent of the roads over the study area (Souza et al., 2005; Souza and Barreto, 2000; Baumgartner et al., 1999). Integrated multi-scale and sensor fusion approaches have been used extensively for automatic road mapping techniques elsewhere (Jin and Davis, 2004). In this study, we plan to test various signal processing and image processing approaches to develop an approach suitable for our proposed study. To verify the validity of the road detection approach, we propose to collect ground data on forest structure and canopy closure within known and active roads within the study area. If the methodology with remote sensing data proves to be erroneous in mapping the sub-canopy roads, we will focus on ground observations, historical data, and other socio-economic data from this study to create a partial map of potential roads within our study area. With the sensitivities available in high resolution optical and radar imagery, it may be possible to extend the directions of routes associated with known geoglyphs into forested areas and to reconstruct some Pre-Columbian upland travel infrastructure. Named *varaderos* from the rubber period can be followed, georeferenced and the vegetation classified and coordinated with field data. Existing and currently used *varaderos, caminos* (intervillage roads) and *trochas* can also be georeferenced. These remotely sensed data can provide a comparative analysis of vegetation structure and types associated with infrastructure of different historical periods. The use of remotely sensed imagery is an increasingly practical means of analyzing forest structure at several different scales and has proved to be a powerful classificatory tool for vegetation analysis and disturbance studies (Buermann et al. 2008; Frohn 2006; Prates-Clark et al. 2008; Saatchi et al. 2008; Saatchi et al. 2007). It has been especially useful in analyzing sub-canopy dynamics including logging.(Asner et al. 2002; Asner et al. 2005; Broadbent et al. 2006; Feldpausch et al. 2005; Grogan et al. 2008; Pereira et al. 2002). Vegetation structure, phenology and productivity can be provided by a combination of radar and optical remote sensing data and can be extrapolated over our study area with data from MODIS (Moderate Resolution Imaging Spectroradiometer). Land use change and deforestation can be generated from current and historical Landsat imagery. These remotely sensed data sets will be integrated with the georeferenced infrastructure. MODIS will be used in conjunction with vegetation analysis for structural characterization to explore the relationships between habitat characteristics, structure, and endogenous infrastructure (Gillespie et al. 2008; Saatchi et al. 2008). This information can potentially extend the results from our sites, and from other regional vegetation surveys ((Bush et al. 2007b; Pitman et al. 1999; Pitman et al. 2001) into an assessment of the impact of sub-canopy infrastructure more generally, and the extent of anthropogenic landscape types in the Upper Purús.

C. ***Historical Ecology: Assessment of the ecological impacts of past and present infrastructure.***

Based on information derived from historical documents, preliminary field research, and remotely sensed images, we believe that throughout the last century the social and natural landscapes of Upper Purús have been shaped by socio-environmental processes that affected stocks of globally traded resources such as rubbers, (especially *caucho*, *Castilloa ulei*), animals (especially of spotted cats and reptiles), and highly valued timbers (especially mahogany, *Swietenia macrophylla* King). These processes and patterns of resource exploitation to supply global markets were and continue to be facilitated by multiple networks of

varaderos and other autochthonous infrastructure. Development, use, maintenance, and in some instances abandonment of these pathways has in turn resulted in change of large areas of Upper Purús forests, especially along fluvial/terrestrial *varadero* corridors. We examine historical and present patterns and uses, and effects on surrounding forests of the network of *varaderos*, *trochas*, *caminos*.

Information collected from archives, and extensive interviews with residents suggests that there is a long and complex history of recurrent and variable resource management of and along the *varadero, camino, and trocha* networks as local populations and economies have developed and declined. The exact periods of creation of many present-day *varaderos* is not known although historical documents identify several as existing well before the Rubber Boom. (Chandless 1866; Markham & Blanchard 1991). *Varaderos* have facilitated access to resources and cheap labor (particularly of indigenous people) since before the rubber period and continue to do so into the current period of booms in conservation, mahogany, and drug trafficking. Apart from the longer-distance, inter-watershed *varaderos*, informants suggest that there are many *caminos* (mostly inter-village paths) and *trochas* (logging roads) that form this infrastructure web. Some *caminos* are undoubtedly ancient while others are new, reflecting frequent disruptions and the mobility of local populations. These were also used by farmers, hunters and loggers during the animal hide boom to access *colpas* or salt licks, and thus this system has been maintained over the last century. In the present timber boom, *trochas* are cut to access manchales (high density clusters) of mahogany, just as they were used to get to and cut *manchales* of *caucho* in the late 19th and early 20th centuries (Flores-Martin 1987; Iribertegui 1987).

We will focus on and compare the ecological effects of the use of *varadero, caminos,* and the more recently constructed logging *trochas*, documenting and comparing variations in surrounding forests, particularly their floristic composition. We hypothesize that a number of specific and important differences will be found to exist between forest plots along *varaderos, caminos, and trochas* and those farther from roadways and less affected by local infrastructure. Some of these expected differences can be summarized as:

1. Depletion of certain economically important species that have been extracted at various times (*caucho*, mahogany, others) along all three types of local infrastructure.

2.. Greater density of some, particularly edible species, along *varaderos* and some *caminos,* particularly around *puestos* or "resource nodes", in some cases resulting in extensive *manchales* or anthropogenic "oligarchic" forests (Peters 1989; Posey & Balée 1989; Rival 2002) reflecting planting and management by users. In contrast, we do not expect to find this difference along *trochas* opened to extract logs.

3. Existence of exotic tree and shrub species within the forest, notably mango, bananas and others, especially along *caminos* reflecting recurrent agricultural production along these pathways, and to a lesser extent along *varaderos*. We explain our methods in detail further in the proposal.

Historical Ecology: Assessment of ecological impacts of past and present infrastructure.

To identify *specific* changes in the landscape and forests along *varaderos, caminos* and *trochas* we will focus the ecological study on: (1) the configuration of landscapes in which roadways are located; (2) characterization of forest types by identifying and contrasting floristic types along *varaderos, caminos* and *trochas,* and (3) determination of the effects of past management and uses on forest composition and structure in and around managed or inhabited areas along the three kinds of roadways. We will assess the ecological impacts of past and present infrastructure in the three *varaderos* mentioned above that link the Upper Purús with the Ucayali, Madre de Dios, and Juruá watersheds (see Map 1); three *caminos* that connect communities (to be selected later), and three *trochas* recently used to extract mahogany, i.e., nine sites in total.

The ecological study in all selected sites will be conducted by a team that will include co-PI M. Pinedo-Vasquez as well as at least one local research assistant who is familiar with local *varaderos, caminos* and *trochas*, a local *matero* or expert on forest biota, a *perito forestal* or forestry technician and one or more local field assistants. The team will be responsible for collecting data on:

1. Landscape Configuration. In each selected *varadero, camino* and *trocha* the team will: (1) trace the route of the road; (2) count and mark the location of *puestos* and any other existing and earlier settlement or agricultural sites; (3) mark and locate physiographic features including areas of poor

drainage or occasional flood. All data collected will be geo-referenced and organized in a multiple entrance matrix. Landscape survey data will be used in conjunction with data from remotely sensed images as well as histories obtained from archival sources and from interviews. Multivariate analysis will be performed to explore complex multi-directional relationships between physiographic features (hills and streams) and road networks (intersections and *puestos*) along sampled *varaderos, caminos* and *trochas*. The analysis will identify how these variables are correlated with different types and levels of forest disturbance or management along different types of roadways.

2. *Characterization of vegetation or forest types.* Along each roadway the local name of specific types of dominant vegetation or forests will be recorded in consultation with the *matero* and verified with other local informants. We expect to encounter several types of the following categories: (1) *manchales* or tracts of forest dominated by economic species such as *caobales* (dominated by mahogany), or *castañales* (dominated by Brazil nut), (2) *colpas* or salt licks, and (3) forests with names reflecting particular cultural meanings (and therefore different management), such as "*monte peligroso"* or "dangerous forest". These data will again be organized in multiple entrance matrices and subjected to canonical discriminant analysis (CDA). The CDA results will reveal specific relationships between the number and assemblage of forest types and resource use intensity over time and space within and among *varaderos, caminos* and *trochas*. The processes that have driven these changes will be explored using historical data collected through interviews and from archival documents and integrated with our remote sensing data, The data collected will be used to construct sketch maps of forest types along the sampled roadways and will be used to inform analyses of remotely sensed images

3. *Forest structure and floristic composition of managed sites along roadways.* Using data derived from the research on landscape configuration and vegetation type, six one-hectare plots (three managed and three control) will be established in each selected *varadero, camino* and *trochas* (54 hectares in total). Plots will be selectively located in areas that have been inhabited, used and/or managed by users of road infrastructure; these will be located in or around *puestos (*along *varaderos), campamentos* along *trochas)* and *chacras* and *purmas* (along *caminos*). While the roadside plots will be hypothetically indicative of the effects of management or disturbance, plots established at a kilometer's distance within the forests will serve as control plots.

Assessments of floristic diversity will be done using stratified random sampling, following standard methods tested in the region (WWF 2007; Mori et al 2007). We will conduct forest inventories in 25 randomly select sub-plots of 10mx10m within each hectare studied, thus covering 25% of the total area of each plot; Mori et al (2007) found that 25% of the total area of a hectare plot is sufficient to derive a reliable estimate of floristic variation in a forested landscape in the Upper Purús (90% confidence intervals). All trees $\geq$10cm DBH will be inventoried and recorded in each randomly selected subplot. We will record local names used by the *matero*, and unknown species will be assigned a number. Three duplicate botanical specimens will be collected for each inventoried species. One duplicate will be deposited at the regional government office in Puerto Esperanza with the others deposited at the herbarium of the Universidad Nacional de Ucayali in Pucallpa and the National Herbarium in Lima. We will identify each morphospecies to scientific species.

For each plot, the following information will be calculated or recorded: a) species richness b) observed disturbance rank, and c) species association type. Next we will conduct a comparison of floral diversity indices across the selected *varaderos, caminos* and *trochas*. Multiple regressions and exploratory nonparametric techniques will be used to explore the potentially complex, multi-directional relationship between floristic composition and structure for each selected roadway type. Results are likely to show that some *varaderos, caminos* and *trochas* will present a range of variation of tree diversity as a result of past logging or other resource use practices. Thus, adjacent sampling units (within the control plots) will be sequentially aggregated and species-log (area) relationships will be used to quantify scale-dependent effects of extraction, management and production of resources in time and space along the selected *varaderos, caminos* and *trochas*. Floristic inventory data will be integrated into a GIS database that will be available for all members of the project team

Research Area: Comparing forest-dependent economies, *varaderos* and anthropogenic vegetation.

A. *Comparative Economies: The White and the Green, the REDD and the Black.* This section analyzes the economic characteristics of the main landscape types found in the region. The "White" economy refers here to the agrarian economies of annual cropping (rice, maize, manioc), and cattle. The Green economy refers to both the waged environmental economy (local direct employment generated through conservation and its linkages) as well as market returns or shadow prices on non-timber products. The REDD economy, refers to payments for environmental services: (REDD, carbon offsets etc.) or possible speculation on environmental acquisitions. REDD refers here to "preservation economies." The Black refers to clandestine economies.

Our research approach to these economies will be multi-scale, and will generate both quantitative and qualitative information. We will generate primary data from livelihood surveys in order to document the contributions of the various forest economies to the household budgets in both marketed and shadow priced goods. We will also survey where forest goods come from, how they are moved, and elicit oral histories of movement as well as current use of the varaderos and their forests. We will also survey for broader natural resources uses (such as thatch, fishing, etc). We will use open-ended interviews; interviews with local merchants and middlemen, and key informant interviews. In addition, regional data at the provincial level; published reports (such as those of conservation agencies) and the large grey as well as formal literature will be consulted. These should provide a snapshot of the magnitude of these economies, their interrelationships, and also their larger relation to and use of forests and of informal infrastructure as sites of resources, of management and of movement. Since the resident population of Purús is relatively small (not much more than 1000 people), but very widely dispersed, we will attempt to interview at least 50% of all households, including 100% of those resident in Puerto Esperanza and the more accessible communities. From this research, which will be integrated with the ecological research, we will be able to ascertain to what degree regional economies rely on earlier ecological architecture associated with endogenous infrastructure. The interviews will also serve to integrate ecological survey data, and larger-scale remote sensing data on endogenous infrastructure and vegetation type with data derived from surveys and local documents.

1. *The White Economy.* This part of the study will rely on well-known approaches to studying Amazonian agricultural production (see for example, Aldrich et al. 2006; Browder et al. 2008; Caldas et al. 2007; Vosti et al. 2003; Vosti et al. 2002) to review 1) costs of production (including deforestation costs); 2) labor demand; 3) available credits; 4) average yields; 5) returns; 6) other land returns including, rents, and land speculative returns; 7) subsistence and market values for crops (Caldas et al. 2007; Harrison 1999; Hecht 1993 ; Pfaff 1997; Simon & Garagorry 2005; Vosti et al. 2002; Walker 2004); 8) shadow values for ecological costs (Costanza 2003; Gavin 2004; Tallis & Polasky 2009). These analyses involve questions of soil nutrient loss, declining yields over time associated with agriculture, and depletion costs associated with mahogany extraction; these will also form part of our calculus.

2. *The Green Economies*. Two forms of "conservation economies" will be used to arrive at an evaluation of their economic contributions: non-timber products and direct conservation payments and conservation linkages. Non-timber forest products will be evaluated for their returns in terms 1) marketed and 2) shadow-priced subsistence returns to NTFPs. Their production costs in terms of labor requirements for management and harvest, will be analyzed, and the types of forests noted, their locations, their distance from settlement and the mode of travel used to reach them (boats, *varaderos*). The PIs all have extensive experience in analysis of the ecological, social and commercial dynamics of NTFPs (Brondizio 2008; Escobal & Aldana 2003; Futemma & Brondizio 2003; Hecht 2007; Hecht & Anderson 1988; Padoch & Pinedo 2006; Padoch 2000; Pinedo-Vasquez et al. 2001; Pinedo-Vasquez 2002; Sears et al. 2007; Shone & Caviglia-Harris 2006; Stoian 2005). The other Green economies are those related directly to the "conservation economy" and to local gazetted parks and indigenous reserves, including the value of linkages to other types of conservation activities including ecotourism. (Ohl-Schacherer et al. 2008; Stronza & Gordillo 2008; Wunder 2000). This will involve research into investments in the sector, payments to formal and casual labor, and an array of linkages associated with the conservation economy, including outfitters, boat rental, guides etc. .

3. *The REDD Economy: Environmental Services*. At this writing there are so far no REDD investments or offsets in part because few formal functioning REDD mechanisms exist, but these are on the agenda in the forthcoming climate talks and regionally, voluntary REDD are underway. However, there are some agents roving the region in search of forests that might be apt for such payments, and for carbon offsets. We suspect that there is a "futures" market that is beginning to operate for forests in the upper Amazon. In any case, calculation of carbon storage through remote sensing, supported by ground-truthing and integrating it into existing models in this region, can provide an interesting comparative scenario about returns to forest uses (Angelsen 2008; Levin et al. 2008; Olander et al. 2008; Osborne & Kiker 2005; Saatchi et al. 2008; Saatchi et al. 2007).

4. *The Black Economy.* The activities of clandestine economies -- both coca and timber -- have a millennial history in Amazonia, but these practices for various reasons have become criminalized. The very high returns, ease of entry into these economies and their globalized nature have made them among the most widespread in the upper Amazon because of the poor returns to other kinds of activities for small farmers. While road building is associated with all four economies, the last three (REDD, Green and Black) are far less reliant on state-financed infrastructure and for quite different reasons (ecological, marketing and legality) prefer "unofficial" infrastructure that maintains forests. It is these economies that dominate the upper Purús.

a. *The clandestine logging economy*. A decades-long timber boom began in the Upper Purús around 1940 and involved a number of timber species including mahogany (*Swietenia macrophylla* King*)*. Exports of logs down the Purús to Brazilian markets diminished and virtually ended when loggers found it unprofitable to access increasingly remote trees and deal with distant buyers in Brazil. A more recent and ongoing timber boom focuses only on mahogany, now a species listed by CITES and requiring a special permit to extract even very limited quantities (AIDESEP 2007). With cross-border trade in timber forbidden (and trade in mahogany banned in Brazil since the 1990s), wood must exit the Upper Purús by air and only mahogany -- almost all of it illegally extracted and headed for US markets -- commands the prices to make this marketing pathway profitable. Recent prices paid for mahogany in the US are almost twice as high as those for any other Amazonian hardwood on the international market (ITTO 2009). Most mahogany from Purús is partially processed *in situ*, carried or dragged to the river and then floated more or less clandestinely to Puerto Esperanza where it is loaded into airplanes for transport to Pucallpa. Research on logging will depend heavily on key informants to determine the volumes and labor demands of the sector; there is also a reasonable amount or grey literature as well as formal literature on this sector, including on the role of conservation areas as preferred sites for valuable timber extraction.(Gutierrez-Velez & MacDicken 2008; Ness 2005; Pedlowski et al. 2005). The co-PIs have been carrying out research on various aspects of timber production and trade in this region of the Peruvian Amazon for the past decade (Padoch et al. 2008; Padoch & Pinedo 2006; Putzel et al. 2008; Sears et al. 2007). we will again build upon our on-going work on timber markets in the region including methodologies developed for understanding the regional impact of Asian timber markets in the Peruvian Amazon (Pinedo-Vasquez et al. 2001; Putzel et al. 2008).

Timber flows, will be measured in several sites and by several methods including the quantification of clandestine flows of timber into Puerto Esperanza, timber shipped by air to Pucallpa, timber transported by river etc. Key informants in the logging industry, including *tabloneros (*chainsaw loggers) and *madereros* (mechanized loggers) will be interviewed and we will develop an analysis of the sectoral structure of the timber economy. We will employ local field assistants (with whom two of us are already working) who have profound knowledge of the structure of the local timber industry and deep ties in local communities.

*b. The clandestine coca trade****.*** While there is little evidence that coca is being grown in Purús in any large quantities, many instances of the use of *varaderos* and *caminos* by coca traffickers have been reported. Recent reconfigurations of drug marketing networks in Peru have resulted in the Brazilian state of Acre becoming the prime destination of semi- and fully-processed coca for sale. The flow through the region involves movement on *varadero* networks. While the volume of the trade may be impossible to

assess, and although there are official figures these remain estimates, its flows through the landscape and labor structure can be ascertained.

Key informant studies of the local economic importance of coca production and transport as well as the structure and dynamics of this industry will be conducted, again relying on local contacts with sufficient knowledge of the coca trade. The delicacy of the clandestine economies is such that we will estimate some flows and values via a series of interviews. We wish to note that the researchers all have been working in the Upper Amazon for many decades (one of us was born in the Ucayali), and have substantial experience in dealing with "invisible economies." The PIs are also fully aware of the importance of protecting vulnerable informants while researching clandestine activities. Several years of working in the region on resource management issues, including coca economies along the Ucayali, have allowed us to develop a number of reliable sources, as well as approaches to data gathering that we believe are adequate to the challenges of the project.

Research Area: Forest economies, their related institutional structures and deforestation.

The comparative economic assessment will certainly provide insight in to the economic logics, but there are other factors at play, including the institutions and forms of governance that mediate land and resources use.

Analysis of Institutions:

1. ***Tenurial regimes.*** We will identify and assess tenurial regimes ranging from indigenous and historical patterns including *seringa*/*caucho* concessions, and other traditional and formal colonist rights, to arrangements within the several types of formally protected areas, and colonist holdings that are now found in the Upper Purús. We will explore the connections of different tenurial regimes with different clearing patterns from remote sensing data as well as interviews. We will also look at whether tenurial forms are shifting from concession, collective and traditional rights to private regimes (or the reverse) and what are the implications of these shifts in terms of clearing, as well as whether access or proximity to traditional infrastructure affect clearing, since the infrastructure literature overwhelmingly connects the two. To answer these questions we will review cadastral records, forms of title, and also compare sites with remotely sensed data and ground-truthing. We hope to map tenurial regimes onto varying forest economies and access patterns that may be associated with varaderos and evaluate how different forms correlate with clearing patterns.

2. ***Forms of governance and clearing.*** We will explore the formal and informal "regulatory apparatus" that affects clearing (enhancing or reducing it) including analyses of political economic coteries, and the impact of the Catholic Church, the military, environmental, and community organizations through extended interviews and examination of state documents and other forms of information and grey literatures. Other interviews will also be fed into our analysis of how access, use and clearing are mediated. In addition, we will consult policy documents and identify informal "regulations."

IV. Implications

A. Theoretical Implications. The Upper Purus is a small region with big implications, and can serve as a case study of how land use and land use history are integrated into both the dynamics of globalization (discourses and markets, both current and past), and into changes in vegetation as an outcome of historical and current structures and processes. The findings about the various types of economies have relevance to many other sites in the Upper Amazon. This research contributes to theoretical issues of several types: 1) it engages on-going debates in Amazonian studies over the impacts of Amazon occupation, and the "natures" of anthropogenic forests through time and space; 2) it expands our understanding of environmental modification by people in Amazonia through impacts along forms of travel modification rather than sites associated with agriculture or urbanism; 3) on a general level it provides inputs into the analysis of resilience in Amazonian ecosystems; 4) it contributes to analyses of political ecologies of governance and resource use including clandestine economies that are often left out; 5) evaluates emergent regional economies in environmental services --REDD and offsets as a part of a new development economy;

6) Our research also explores the "natures" of institutionalities in the Upper Purús, and thus can contribute to a dynamic literature on land use, institutions and resource governance.

B. Broader implications. Apart from expected contributions to theory, our work will provide potentially invaluable socio-environmental baseline studies for monitoring land use changes in the Peruvian Amazon, especially as large infrastructural programs such as IIRSA affect the forested interior of Amazonia. Our work with students, both US- and Peru-based will help them develop a distinct set of multidisciplinary skills and research approaches. Finally, we believe that much of our research could contribute to a reanalysis of infrastructure planning in the upper Amazon and provide governmental and non-governmental agencies at various levels new ideas and new tools for developing different, effective, and efficient forms of transport and trade. We view understanding indigenous transport systems as having insights akin to those of indigenous knowledge of production systems.

V. Suitability of Principal Investigators for Proposed Research

The PI's have all worked and lived extensively in the Amazon and written on the ecologies and economies of peasant, indigenous as well as corporate land uses and strategies. They have been influential in the debates about Amazonian settlement and history, traditional knowledge systems and development alternatives for the region. They have had long and regular Amazonian presence that created durable links with many Amazonian education and research institutions in Peru and Brazil. Dr. Pinedo-Vasquez is a native of the Ucayali region where the research will take place and has extensive ties with a variety of government and non-governmental organizations and their leaders. He has worked on forest management, including trade in timber and non-timber forest products. Dr. Saatchi has trained many of Peruvian and Brazilian researchers in remote sensing, and his own work has helped define the field, especially in the use of Radar technologies for vegetation discrimination, subsurface material discontinuities and carbon storage. Dr. Hecht has held positions at several Brazilian Universities (UFPA, UFMG, USP) and research institutes (Museu Goeldi and CEDPLAR). She has worked actively on research and development questions in the States of Acre and Para, and has just finished writing a book on the history of the Purús as part of the "Scramble for the Amazon." She has trained numerous Brazilian and expatriate American specialists in Amazon studies. Dr Padoch has spent several decades working on resource use, migration, and trade in minor forest products in the Peruvian and Brazilian Amazon, including the last five years in the Ucayali Region near the Purús. All the researchers have extensive experience with integrative multidisciplinary work. This experience will pay off in this project in terms of efficiency in getting information, and in the sophistication of the analyses.

VI. Linking Research to Education

The project will produce important results not only for scientists and students in several fields, but also for regional and local governments, development and conservation organizations, and local indigenous and non-indigenous communities. We will therefore include multiple activities and produce a variety of products with an educational and training focus. These activities will include:

A. The project team will integrate Ph.D and MA students in the research. These students will include project activities in their MA theses and dissertation research. UCLA students will come from Departments of Planning, Public Policy, Geography and the Institute of the Environment. A project such as this is also relevant for students in International Planning, and Regional and Community Development. Students will be funded through their own projects with the Latin American Center, the Burkle Center for International Study, the Center for Globalization and the Center for Tropical Research at UCLA.

B. We will involve students in our ecological field research and in the analysis of our results. Funds for summer training of Columbia University students will be made available by that university. We also expect to work with graduate students from other US and Peru-based institutions doing longer-term thesis research in our focus sites.

C. We will coordinate student-focused field training activities with the administration of the Universidad Nacional Intercultural de la Amazonía (UNIA), a University in Pucallpa dedicated to educating the youth

of indigenous and local communities. The two Co-PIs have already begun talks with the Rector and Vice-Rector of UNIA about the possibilities of including UNIA students in this and other projects.
D. The project will feature briefing sessions for local decision-makers as well as technical personnel of regional and local governments and NGOs including the Purús provincial indigenous organization, FECONAPU. The Co-PIs have multiple existing ties with regional government and non-government institutions and leaders, and have already collaborated with them.

VII. Dissemination of Results

We will produce a substantial number of scholarly articles as well as summaries in Spanish of our publications and relevant pieces of our project reports for local authorities and organizations in the Amazonian region. These reports disseminated by email to mailing lists. We will establish a project website at UCLA's School of Public Policy, International Institute, and the Institute of the Environment which will provide greater access to our findings. Finally, as described above, we will conduct training and workshops for local decision makers, technical personnel, members of local, including, indigenous organizations, and rural community members.

VIII. Results of Prior NSF support

Co-PIs M. Pinedo-Vasquez and C. Padoch participated as PI and co-PI, respectively, in an NSF-HSD (Agents of Change) project entitled: "Global Markets, Regional Landscapes and Household Decisions: Modeling the Transformation of the Amazon Estuary." This project examined the connections between external markets, the emergence of a forest economy, and the re-organization of households and rural-urban social networks in the Amazon. The project generated many publications, among them: Pinedo-Vasquez, M., E. Brondizio, C. Padoch, and M. Ruffino. In press. *Development and Conservation of the Amazonian Floodplains: The decade past and the decade ahead.* Springer Publishers; Padoch, C., E. Brondizio, S. Costa, M. Pinedo-Vasquez, R. R. Sears, and A. Siqueira. 2008. Urban forest and rural cities: multi-sited households, consumption patterns, and forest resources in Amazonia. *Ecology and Society* 13: [online]; Pinedo-Vasquez, M., and C. Padoch. 2009. Urban, rural and in-between: multi-sited households, mobility and resource management in the Amazon floodplain in M. N. Alexiades, ed. *Mobility and Migration in Indigenous Amazonia*. Oxford, Berghahn.

Educational Achievements of Prior NSF Research The project's training component included the participation of 3 post-docs, 4 graduate students, 6 undergraduate students, and 6 local interviewers. It also featured workshops for farmers and leaders to show project results. Pinedo-Vasquez and Padoch worked with undergraduates at Columbia University on survey data from this project, conducted 5 two-week training courses for undergraduates at the State University of Amapá and 2 at the Federal University of Pará. Ninety Brazilian students attended these courses. Four graduate students were trained; one (working with Padoch) completed her Ph.D.; three are still in progress. Two post-docs were trained, one each from Brazil and the US. Broader Impacts of Prior NSF Research Three training courses on land and market surveys for local rural extension agents were held. Total participants included 32 rural agents working for the state agency and 14 working for NGOs. Five training courses: three on land-use and urban expansion for undergraduates at the State University of Amapá and two on rural development at the Federal University of Pará were also held; approximately 90 Brazilian students attended these courses. The last year of the project 4 workshops for journalists and policymakers from the state of Amapá were held. About 120 individuals attended. Additionally, National Public Radio visited the field sites and broadcast a story about the project on NPR's Morning Edition in February 2008, exposing the project to a broad lay audience in the US.