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Constraints and opportunities for better silvicultural practice in tropical forestry: an interdisciplinary approach

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Abstract

Barriers to successful adoption of novel silvicultural practices are rarely just technical in nature. Simply put, why do some forest users practice better silviculture than others? Diverse perspectives in the social sciences have been brought to bear on this question, but most efforts suffer from theoretical or methodological biases which undermine their utility for answering questions of interest to forest managers and policy-makers. We argue that research on silviculture practice can better serve the needs of policy-makers if it is approached more holistically and with the intention of answering clear questions about why particular users have, or have not adopted desired practices in particular situations. To illustrate this approach, we present three case studies of research on tropical silviculture practice from each of Philippines, Brazilian Amazon and Mexico. Findings from these studies indicate that a variety of factors may influence whether or not silvicultural practices are adopted. These range from characteristics of the local environment and individual users (knowledge, motivation, etc.) to wider geographical, economic and political influences. Forest researchers and policy-makers will better identify key constraints and opportunities for the adoption of silvicultural practices in particular contexts if they approach research with clear questions and an interdisciplinary approach.

Keywords: Silviculture; Diffusion of innovations; Research methods; Community forestry; Natural forest management; Tropical forests; Mangroves; Mahogany

1. Introduction

Research on tropical forest silviculture has focused primarily on questions of technical efficacy (Nair et al., 1995). Implicit in much of this work is the assumption that obstacles to successful forest management are technical in nature. Yet, research that considers the relative uptake of such practices in real world settings suggests that the adoption of improved silviculture by targeted end-users cannot be taken for granted. In fact, a theme which cross-cuts most research on the adoption and diffusion of novel silvicultural and related practices is that barriers to

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successful practice are rarely purely technical in nature (Saint and Coward, 1977; Poore et al., 1989; Walters, 1997; Potter and Lee, 1998; Walters et al., 1999; Blundell and Gullison, 2003; Pattanayak et al., 2003; Song et al., 2004).

Why do some forest users practice better silviculture than others? Diverse perspectives in the social sciences have been brought to bear on this and related questions. Studies on the diffusion of rural innovations like tree planting are varied in their theoretical orientation, methodology and findings (Mercer, 2004). Briefly, these can be grouped into six general perspectives, although admittedly many individual studies cross-cut more than 1 (Agarwal, 1983; Yapa, 1996). Early studies of agricultural innovations emphasize a ‘‘straight transfer’’ approach, which assumes novel practices are desired by targeted users. Failure to adopt is thus viewed as a shortcoming of those users (e.g., ignorance, irrationality, risk-aversion), which can be overcome with persuasion and better information sharing (Lionberger, 1960; Rogers, 1969).

By contrast, the ‘‘appropriate technology’’ perspective assumes that rural people behave rationally, but this rationality can only be understood in terms of the specific socio-economic and ecological context within which potential adopters make decisions. This view has prompted a great many studies which attempt to explain variable adoption rates in terms of differences in the socio-economic characteristics of targeted users (e.g., Godoy, 1992; Amacher et al., 1993; Caveness and Kurtz, 1993; Current, 2000; Pattanayak et al., 2003; Mercer, 2004; Summers et al., 2004; see also Feder et al., 1985). Proponents of this perspective would encourage user input into technology development to better the match. Taken to one extreme, appropriate technology merges with the ‘‘indigenous technology’’ perspective, which assumes that local peoples’ knowledge and practice is rich with potential for addressing many rural development and resource management challenges. Researchers from this perspective concern themselves less with questions about why people are or are not adopting modern technologies, and more with questions about local knowledge systems and ways to promote these (e.g., Redford and Padoch, 1992; Sillitoe, 1998; but see Vayda et al., 2004).

The ‘‘induced innovation’’ perspective is influenced heavily by neo-classical micro-economic theory and the common observation that innovations tend to emerge and spread rapidly in response to economic scarcities (Boserup, 1965; Ruttan and Hayami, 1984; Mercer, 2004). One thus expects to find land management intensification through silviculture in cases where forest resources per capita are in decline (Romm, 1989; Netting, 1993; Arnold and Dewees, 1995; Rudel, 1998; Walters, 2003; Summers et al., 2004). In contrast, ‘‘geographic’’ perspectives emphasize context and the importance of spatial factors, such as proximity to markets or migration of people, for explaining patterns of innovation spread (e.g., Hagerstrand, 1967; Brown, 1981). Finally, the ‘‘political economy’’ perspective argues that innovations must be understood in relation to larger socio-political structures and government policies as these can determine who has access to novel practices and whether or not they will have incentive to adopt them (e.g., Blaikie, 1978; Gregory, 1985; Blundell and Gullison, 2003).

2. From discipline-driven to question-based

These different perspectives have enlarged our understanding of the factors affecting the adoption of silviculture practices. Yet, taken individually they provide only limited guidance to policy-makers and managers faced with the practical challenge of promoting silviculture in particular local or regional settings. This is because real world settings are complex and varied, and policy-makers need to understand this to predict whether specific practices are likely to be adopted by targeted end-users. In short, the adoption and diffusion of novel silvicultural practices needs to be understood as a historical process, unfolding differently in different places.

This challenge is exacerbated by a lack of integration between the aforementioned perspectives. Many studies span more than one perspective, but few are sufficiently interdisciplinary to integrate the insights of all of them. Instead, most studies rely on theories and methods that preclude effective integration: anecdotal accounts which confirm pre-determined theories; data collected to evaluate pre-designed models; or point-in-time surveys which correlate user characteristics with adoption decisions.

We argue in this paper that research on the adoption of silvicultural practices can better serve the needs of policy-makers if it is approached more holistically and with the intention of answering clear questions about why particular users have, or have not adopted desired practices in particular situations. This approach strives to minimize a priori theoretical biases about which factors are more or less likely to be important. It also shuns disciplinary prescriptions about appropriate methodologies for studying silvicultural adoption. In short, it downplays the significance of general theory and method as either a guide or ultimate goal of research on silvicultural adoption.

Instead, we propose that researchers embrace a range of theoretical possibilities and deploy diverse methods as required to explain the adoption (or non-adoption) of particular silvicultural practices in particular contexts (Vayda and Walters, 1999; Vayda et al., 2004; Walters and Vayda, 2004). In so doing, researchers should embrace an eclectic methodological strategy, deploying whatever qualitative and quantitative methods are available to them and best suited for answering questions of interest. Guided by open-ended "why" questions, researchers can then consider the potential influence of diverse local and non-local influences (e.g., technical or environmental constraints; individual users' knowledge or motivations; wider political events or policies, etc). They can identify with precision and in particular contexts the key mechanisms that have fostered adoption of desired practices, as well as critical barriers or constraints to such adoption.

By "open-ended why questions", we are not suggesting that the basis for all such research be the posing of why questions to silvicultural users, although that may be an important aspect of the larger investigation. Rather, we mean that the overall investigation be guided by researchers first asking themselves "why" silvicultural practices are being adopted or not in particular situations. Answers to this question may be derived, in part, from field-based inquiry whereby users are asked about their decisions to adopt or not. It may also include ethnographic or statistical investigations which probe the deeper relationship between adoption decisions and other local and non-local influences. As well, it might include consultation of secondary sources, professional opinion, historical documents, and so forth. Pragmatic as much as disciplinary considerations will determine which methods are employed and which sources consulted (Hawthorn, 1991; Vayda, 1996). In short, researchers may consult diverse information sources and deploy any number of practical methods that are seen as useful for answering questions of interest.

To illustrate our arguments, consider a recently published review of agroforestry adoption research by Pattanayak et al. (2003). These authors acknowledge that "... agroforestry adoption is a complex process that can only be truly understood and explained using multiple methods and data (quantitative and qualitative), not just statistical models of household survey data" (p. 148). Yet, their formal analysis of the literature is restricted to only those studies which deploy quantitative, ex-post user surveys as the research method. The result: their entire "review" of the literature boils down to a summary of selected, abstract user characteristics which are, statistically speaking, more or less likely to correlate with adoption.

It is difficult to fathom what policy-makers are supposed to do with such de-contextualized information. Our own experience with ex-post, correlation studies like these is that they beg more questions than they answer about why people with particular characteristics choose to adopt or not in particular situations. Characteristics like "education", "income" and "tenure", while not especially strong predictors of adoption anyway, are only really meaningful in the context of adoption decisions when it can be understood "why" or "why not" said characteristics lead to greater adoption in particular cases, but not in others (Walters et al., 1999). But this is the nature and general limitation of research that is driven more by disciplinary imperatives (quantitative, micro-economic analysis, in this case), than out of desire to understand why particular people are choosing to adopt or not in particular contexts (Quinlan and Scogings, 2004).

In making these criticisms, we do not suggest that such studies are not valuable, nor that what we are proposing as an alterative represents a "holy grail" for adoption research. To the contrary, we admit that our approach will lead only to partial explanations of phenomena in question, and that findings may not be readily applicable elsewhere. Nonetheless, we believe that too much emphasis has thus far been placed on approaches, which in their striving to further general theory within their own disciplines, have to a significant extent compromised the understanding of the particular cases at hand. Yet, it is the particular cases at hand that rural development agents and policy-makers are usually concerned with.

The following three case studies will illustrate the application of our more pragmatic and interdisciplinary approach to studies of the adoption of silvicultural practices in forests. Cases are drawn from diverse geographic and socio-political settings and consider a wide range of systems, including small-scale mangrove management in the Philippines, timber forestry in the Brazilian Amazon, and community forest management in Mexico.

3. Mangrove tree planting and management in the Philippines

Silviculture of mangroves is relatively uncommon, but policy-makers in many countries increasingly view it as essential to addressing challenges of mangrove restoration and management (Weinstock, 1994; Hussain, 1995; ITTO, 2002). In the Philippines, two sites—Bais Bay and Banacon Island—have been widely showcased as successful models of mangrove silviculture. Both sites have long-established histories of mangrove planting and management involving widespread local participation (Walters, 2004). Attempts by government and non-government organizations to emulate these success stories elsewhere in the country have multiplied since the early 1980s, yet met with little success (Calumpong, 1994; Primavera and Agbayani, 1996, personal observation). Research was undertaken by Walters in 1997 to better understand the particular cases of mangrove silviculture in Bais Bay and Banacon Island.

More specifically, Walters sought to explain why mangrove planting and management had emerged and spread in cases where it had, but not in others. To answer this question, he deployed a variety of methods, including semi-structured interviews of planters and key informants in a dozen villages, systematic household surveys of select villages, reviews of government records and other secondary sources, and extensive forest and environmental assessments of mangrove plantations and planting sites (for a detailed description of methods, see Walters (2000a, 2003)). The following summarize some key findings from this study.

Rhizophora species, locally referred to as *bakau*, are by far the most commonly planted mangroves in Bais Bay (*R. mucronata*) and Banacon Island (*R. stylosa*). These species are particularly valuable for construction wood and easy to plant, and seed sources are locally abundant. Trees of other species are rarely planted and, where they already exist naturally, are typically planted around or deliberately cut back to make more space for planting *Rhizophora*. Harvesting is done selectively or, increasingly on Banacon Island, in small clear-cuts (Walters, 2005). Since planting establishes a degree of tenure to otherwise common lands, cut areas are typically replanted quickly to ensure site claims are not lost to others. The degree of post-planting management varies, with many leaving stands essentially unmanaged as they grow and others practicing stem thinning and understory weeding (Walters, 2004).

Evidence suggests that early planting emerged in the early–mid-1900s and spread within Bais Bay and Banacon Island in large part as a response to scarcities of construction wood, especially for use in *bunsods* (fish traps). These scarcities were exacerbated by growing populations and the imposition of commercial firewood concessions over extensive natural forests in each area although the clearing of mangroves for fish ponds were a major factor in Bais Bay. Yet, this insight is of only limited value to policy-makers. After all, if resource scarcity is all that is required to motivate local investments in mangrove silviculture, why are such practices so uncommon in a country that has experienced over 70% loss of mangroves (Baconguis et al., 1990) at the same times as population densities have exploded along the coast?

Resource scarcity is undoubtedly a factor, but careful examination of the local cases reveals a more complex picture. First, it is apparent from household interviews that motivations to plant vary among individuals and between villages, and these motivations have changed over time. For example, planting mangroves for bunsod posts remains an important motivation for many people, but since the 1960s increasing numbers have been motivated to plant for other reasons, notably to protect homes and fish pond dykes from storm waves and winds; to establish tenure claims over mangrove areas, and appease government

Table 1
Motivations to plant mangroves according to respondents in different villages in Bais Bay and Banacon Island, Philippines

Motivation to plant	Village				All sites (n = 156)
	Canibol (n = 43)	Olympia (n = 20)	Sanlagan (n = 30)	Other villages (n = 63)	
Storm protection	69.7**	35.0	30.0	44.4	47.4
Wood for bunsod construction	25.6*	70.0*	53.3	41.3	42.9
Told to plant by officials	21.0	0	16.7	11.1	13.5
Source of fuel wood	2.3	25.0	23.3	7.9	11.5
Tenure security	9.3	10.0	0.0	14.3	9.6
Capital investment	4.7	0.0	16.7	12.7	9.6
Other construction wood	2.3	0.0	10.0	9.5	6.4
Paid to plant	0.0	0.0	10.0	6.3	4.5
Land speculation	0.0	0.0	0.0	7.9	3.2
Amusement	7.0	5.0	3.3	0.0	3.2
Good for ecology	0.0	5.0	0.0	3.2	1.9

Figures represent the percentage of respondents indicating said motivation. Statistical tests compare differences between villages for each motivation (i.e., chi-square comparisons between the individual observed village frequencies and expected frequencies based on all sites combined).
* $p < 0.05$, d.f. = 1.
** $p < 0.005$, d.f. = 1.

officials who have promoted planting under various programs (Table 1). As well, planters on Banacon Island increasingly sell wood to off-island buyers who use it for construction of wharves, beach resorts, etc.

Eighty-three percent of respondents interviewed (171 of the 205) had planted mangroves, although some were unsuccessful in their efforts (i.e., >80% mortality of planted seedlings). Attempts to correlate participation or success in mangrove planting in terms of basic socio-economic characteristics (e.g., income, household size, education) proved unhelpful (Walters, 2000b). Explanations for varied participation and success thus had to be sought elsewhere.

Mangrove planting is not a technically complex task. In fact, only 4 of the 35 respondents (11.4%) who had not planted mangroves cited as a reason the lack of knowledge about how to plant. Nonetheless, planters varied much in terms of their knowledge and experience and this was found in cases to influence their relative planting success (Vayda et al., 2004). Mangrove planting in most villages was introduced and continues to be practiced most vigorously by a minority of intelligent, entrepreneurial persons. These ‘‘leaders’’ got the initial idea to plant either by observing others in neighboring villages or from observations of natural reproduction in nearby mangroves. Beyond just introducing planting to new areas, their innovativeness extends to various planting-related practices, including the deliberate test-planting of different sites and substrates, comparing varied spacing distances, and so on. Other planters often cited these persons as having imparted to them the initial idea and motivation to plant, although subsequent followers are typically cautious and slow to imitate the practice, remaining unconvinced until wood from the plantation is actually harvested by the original planter. Such ‘‘waiting and seeing’’ before actually investing planting effort is a sentiment that was frequently expressed by respondents in the study, and it was similarly documented in research on tree planting and soil conservation adoption in the nearby uplands (Walters et al., 1999).

Surprisingly little intentional knowledge sharing occurs among planters. Instead, the idea and basic knowledge to plant or adopt specific planting practices is either self-taught or, more likely, acquired by observing and imitating others who had successfully done so already (Table 2). In fact, nearly nine times more people cited having imitated planting from a neighbor as cited having been taught how to plant from a neighbor. Likewise, many planters indicated that they learned—typically as children or adolescents—by simply observing their parents plant, but only half as many claimed that their parents actually explained to them how to plant. These patterns of learning probably explain why highly visible practices, like planting or using fish net as fences to protect young trees, are widespread where practiced; while

Table 2
Sources and mechanisms of learning about planting mangroves according to mangrove planters in Bais Bay and Banacon Island, Philippines

Source of learning	Mechanism of learning		
	Taught how to plant	Imitated planting	Personal experience
Neighbor	4.7	41.5	–
Parent	16.4	27.5	–
Government official	10.5	1.8	–
Other relative	4.1	4.1	–
Sibling	0.6	1.2	–
Grandparent	1.8	1.2	–
Friend	1.2	0.6	–
Employer	1.8	0.0	–
School teacher	1.8	0.0	–
Learning by doing	–	–	40.9
Experimentation	–	–	8.2
Nature observation	–	–	8.2

Figures represent the percentage of respondents ($n = 171$) indicating said source.

other techniques, more subtle yet potentially valuable, are not (e.g., appropriate spacing distances or application of oil to prevent *sisi* infestation).

But the provision of opportunities to learn how to plant is still sometimes insufficient to motivate planting or ensure planting success, even where there exists clear incentives to do so. For it was further learned that many potential planters were prevented from doing so because all nearby foreshore lands had been claimed by others and either developed into fish ponds or planted in mangroves. Under Philippine law, mangroves are technically public land, but the government allocates leases for fish pond development and mangrove management. Areas not under such formal lease are, nonetheless, sometimes claimed and defended by private interests. One way to assert informal claim to an area is to plant mangroves on it. There were even cases where allocation of tenure leases for the purpose of encouraging mangrove planting emboldened leaseholders to clear mangroves for other purposes (fish ponds, residential settlement). In short, competition for space and tenure uncertainties provide incentives to plant mangroves in some cases, but disincentives in others.

Access to suitable planting areas was also found to be an ecological matter. Specifically, environmental assessments confirmed planters' claims that many sites are simply unsuitable for growing mangroves. Young seedlings, in particular, are vulnerable to any one or a combination of stressors that will kill them, including storm waves, shell infestation, entanglement by floating seaweeds and anthropogenic disturbance. Planting is thus futile in many sites, regardless of peoples' technical knowledge and motivations.

In summary, research findings suggest that efforts to promote mangrove planting and management are more likely to succeed where there exists a clear demand for exploitable mangrove resources among targeted users. This is likely to be the case in areas experiencing relative scarcity of mangroves, but also where markets exist for valued products and services (i.e., mangrove wood is banned from commercial trade in the Philippines today, but informal local markets and household consumption continue in many places). Planters tend to learn mostly by observation and imitation, which makes the role of successful demonstration planting critical. But even where these conditions are met, planting and management of mangroves may not be embraced widely if areas suitable for planting are unavailable. Ecological conditions often preclude successful planting, and in many areas suitable habitat is already mostly claimed for strict conservation, buffer zones, fish ponds or other forms of development. Until these conditions change as a result, for example, of releasing fish ponds for reforestation (Stevenson et al., 1999), prospects for expanded mangrove silviculture in the Philippines are probably quite limited.

4. Silvicultural practice in the Brazilian Amazon

Indigenous inhabitants of the Amazon have practiced silviculture for centuries (Posey, 1983; Balee, 1989). However, state-sponsored silviculture in the Brazilian Amazon began only several decades ago, and mainly focused on experiments in natural forests that sought to induce or promote growth and regeneration of desirable timber species (e.g., Pitt, 1961; Silva, 1989; Silva et al., 1996). In spite of the considerable accumulated research and experimentation efforts with various silvicultural options (e.g., Eden, 1982; Kanashiro and Yared, 1991; Silva et al., 2001) and the legal obligations to undertake post-harvesting silviculture in managed forests (Lopes, 2000), natural forest management has until recently received little attention by forest users. Most silvicultural practice in the region today is associated with tree plantings—commonly forest plantations established by the private sector and agroforestry combinations as part of farmers' production systems (Anderson, 1990; EMBRAPA/FUNTEC, 2001; Simmons et al., 2002; Summers et al., 2004; Sabogal et al., 2005). Natural forest silviculture is limited to isolated initiatives of better organized forest enterprises and progressive small-scale farmers in older settlement areas (e.g., Almeida et al., 2005).

This study was undertaken by Sabogal and Almeida to identify and evaluate silviculture practices being used by forest enterprises and small-scale farmers in different contexts and, specifically, to gain a better understanding of factors influencing their wider adoption. In other words, why is silviculture more likely to be practiced by some land users than others? To address this question, an inventory of silvicultural cases in the Brazilian Amazon was compiled based on an extensive literature survey, interviews of key informants, and a questionnaire distributed to relevant institutions, local organizations and individuals. From this, a database was compiled comprising 275 different cases across Legal Amazonia (an area comprising 8 states and a total surface of 500,000 ha). These cases ranged from research trials to efforts carried out by forest enterprises and small-scale farmers in the uplands (*terra firme*) and floodplains (*várzea*) (Sabogal et al., 2005; Almeida et al., 2005).

From this database, Sabogal and Almeida selected for study 66 different cases across four states (Pará, Rondônia, Amazonas and Mato Grosso), which satisfied a set of minimum criteria (e.g., at least 2 years since establishment, use of native tree species, minimum size of 1.0 ha for forest enterprises and 0.5 ha for small-scale farmers, and reasonable access). Each of these cases was subsequently visited by researchers who conducted semi-structured interviews with responsible persons (managers, technicians, farmers) and carried out field observations and measurements. The collected data was stored in a database in access and analysed using a commercial statistical package.

In the 66 cases evaluated a wide range of experiences was found. Fifteen silviculture "types" were identified, including pure (single species) and mixed forest plantations established on land previously used for subsistence crops, pasture or secondary forest (or second-growth forest, locally called *capoeira*); enrichment planting in second-growth and primary logged-over forest, and tending of natural regeneration of desirable species in the same forest conditions. Over half of the experiences consisted of pure forest plantations established on abandoned pasture or capoeira land. These also occupied much larger areas than other silvicultural undertakings. Examples of treatments to foster natural regeneration and enrichment planting were concentrated in the so-called "legal reserve" defined by IBAMA (according to the existing regulation, 80% of any rural property in the Amazon region must be kept under forest and this *Area de Reserva Legal* can only be used for forest management or conservation purposes). The forest species used in these silvicultural options are managed within a large area generally of logged-over forest. Enrichment planting takes place mainly in gaps created by tree felling or along skid trails.

Altogether, 75 forest species were silviculturally managed, most of them native to the Amazon. *Pschizolobium amazonicum* (paricá) and *Swietenia macrophylla* (mahogany) are the most commonly planted species. The ease of getting seeds together with their fast growth, easy management and adaptability, plus a good market price, contribute to the increasing preference for these species by both forest enterprises and small-scale farmers. *Bertholletia excelsa* (Brazil nut), *Ceiba pentandra* (samaúma), *Dipterix odorata* (cumarú), *Cordia goeldiana* (freijó), *Carapa guianensis* (andiroba), *Cedrela odorata* (cedro), *Tabebuia* spp. (ipê amarelo and ipê roxo), *Bagassa guianensis* (tatajuba), among others, were also species frequently planted in the visited areas. The preferred exotic is teak (*Tectona grandis*), with over 13,000 ha estimated planted area in Mato Grosso State alone. The African mahogany (*Khaya ivorensis*) is a timber species also in demand and so desired by many landowners wanting to reforest their lands.

What motivates land users to plant trees or tend natural forest regeneration? Respondents gave several explanations (Table 3). Enterprises, mainly involved in commercial tree planting, were primarily motivated to plant to secure medium to long term supply of raw materials, although the obligation by law to replace

Table 3
Motivation to plant or tend natural regeneration according to forest enterprises and small-scale farmers in four states of the Brazilian Amazon

Motivation to plant/tend natural regeneration	Enterprises ($n = 38$)[a]	Farmers ($n = 28$)
Secure medium/long term wood supply	24	12
Obligation by law	22	–
Reforest the property	10	24
Voluntary forest reposition	10	–
Investment for the future	6	27
Raw material close to the industry	6	–
Extractivism	6	7
Heritage for their children	2	10
Shade	–	7
Other reasons (timber marketing, forest certification, etc.)	14	13

Values are in percentage.
[a] Two experiences from research institutions were not included.

Table 4
Factors constraining the implementation of silvicultural practices according to forest enterprises and small-scale farmers in four states of the Brazilian Amazon

Constraining factor	Enterprises ($n = 38$)	Farmers ($n = 28$)
Lack of technical assistance	19	6
Pest attack or plant disease	18	24
Lack of knowledge about the species planted	18	12
Difficulty to acquire seeds and seedlings	12	28
Lack of knowledge about seed germination and seedling production	9	12
Plantation management	9	6
Convince small-scale farmers to initiate the experience	3	6
Adaptation of labor for working in the forest	–	6
Other factors (e.g., lack of incentives, inadequate soils)	12	–

Values are in percentage.

trees extracted from natural forests by planting was also an important incentive. By contrast, small-scale farmers were mostly planting or tending the regeneration of preferred tree species as part of their agricultural systems (to reforest the land). Silvicultural practice was viewed typically by them as an investment in the future for the benefit of their children and grandchildren. Planting was also viewed by many as a means to strengthen tenure claims to land.

Although with some differences in importance, the factors most frequently cited by respondents as constraining successful implementation of silvicultural practices were the incidence of pest attacks and diseases, difficulties in obtaining and manipulating planting material (of native forest species), and lack (or low quality) of technical assistance (Table 4). Lack of technical knowledge about the silviculture and management of native tree species was also a limiting factor for both groups of land users. For example, it was learned that only very few enterprises which have invested in reforestation know the techniques for collecting and processing forest seeds and for plant production. Lack of financial incentives or difficulties in accessing credit were less frequently cited as problems, despite the fact that most cases of silvicultural management (82%) were self-financed (i.e., did not receive any type of external funding).

Over half of respondents apply some form of post-planting management. This is mainly restricted to site cleaning/weeding (85%). In only few cases do forest enterprises carry out the full range of silvicultural measures (including pruning, thinning, sanitary treatments, etc.). Labor constraints were cited as the main reason for lack of site management, followed by high costs for applying practices. Pest attacks and disease were considered the main problem affecting the maintenance of forest sites, and especially impacted the two most frequently planted species—*P. amazonicum* and *S. macrophylla*.

Nevertheless, 86% of respondents indicated a desire to continue practicing silviculture. In fact, many enterprises were increasing their planted areas, sometimes buying more land. Others viewed with optimism the possibility to invest in the timber sector given the rising prices of valuable timber such as mahogany, ipê and angelim. The availability of appropriate/relevant technical and economic information on selected native tree species and techniques;

strengthening of existing networks for seed banks and seedling production; establishment of well designed extension programs, and access to financial resources and key adaptations in the legal framework were among the most needed recommendations given by forest users and other relevant stakeholders in order to encourage the development of a viable, competitive silviculture in the region.

5. Mahogany silviculture in Quintana Roo, Mexico

The state of Quintana Roo, on Mexico's Yucatan peninsula, is 74% forested (Jhones et al., 2000 in Bray et al., 2004), and produces 32% of Mexico's precious tropical timbers (about 8000 m^3/year of mahogany, *S. macrophylla*; Nolasco et al., in press), as well as some cedar, *C. odorata* (INEGI, 1990:6). Forty-six percent of Quintana Roo is controlled through communal land ownerships called 'ejidos' (INEGI, 1991:6). Since the mid-1980s, these ejidos have had the legal right to carry out industrial timber harvesting on their forests. As of 2003, 127 ejidos, with a population of approximately 14,000 people, have done so, defining and managing permanent forest reserves totaling more than 730,000 ha of natural tropical forest (Nolasco et al., in press). Some ejidos have sawmills and sell boards, while others sell logs of mahogany and about 20 other species. In addition, some ejidos cut and sell railroad ties from species with durable woods. Most also obtain income from the harvest and sale of non-timber forest products (chicle latex from *Manilkara zapota*, palm thatch, building poles, and honey). Mahogany sales yield the largest portion of earnings among all these categories of forest products, accounting for approximately 25% of the state total of US$ 11.7 million in 2003 (Nolasco et al., in press).

In contrast to the situation in South America (described by Blundell and Gullison (2003)), many Quintana Roo ejidos are applying and refining silvicultural techniques to sustain mahogany in their natural forests. This case examines why Quintana Roo ejidos, in general, have applied mahogany silviculture, and why some ejidos, in particular, have advanced further than others. Findings are based on questionnaires applied in 2003 to 5 foresters responsible for management of the forests of 54 Quintana Roo ejidos (of which 21 currently harvest mahogany), and to representatives of state and federal government agencies responsible for regulating and overseeing forest management. These are complemented by insights from presentations and discussions by foresters, representatives of government agencies, members of the forestry ejidos and researchers during 3 days of workshops and field visits in which results of silvicultural research on mahogany regeneration were discussed (Snook and Lopez, 2004), and the articles written by participants for the proceedings of this workshop (Snook and Navarro, in press). Additional insights derive from observations obtained during 20 years of research in various ejidos of the region.

Forest management plans for the Quintana Roo ejidos are built around three components: a 25-year cutting cycle; annual harvest volumes by species group, derived from forest inventories; and minimum diameter limits which vary among species and by end use. Silvicultural aspects of forest management plans focus principally on mahogany because it is the most valuable timber resource, and its ecological characteristics make its regeneration a challenge (Snook, 1996). Concern about the lack of post-logging regeneration was a major reason for the listing of mahogany on Appendix II of the Convention on International Trade in Endangered Species in 2002 (Snook, 1996; Blundell and Gullison, 2003). Mahogany is a light-demanding species with wind-dispersed seeds, which has been found to regenerate abundantly after disturbances that produce clearings. In this region, these have typically resulted from hurricanes followed by fire, or shifting cultivation (Snook, 2003). Selective harvesting, by contrast, typically creates small gaps, which open only about 2% of the canopy (Whitman et al., 1997; Dickinson et al., 2000).

Silviculture, consisting primarily of enrichment planting, was initiated as part of the community forestry activities in the mid-1980s. About February, ejidos collect mahogany seed from felled or standing mahogany trees. A number of ejidos have nurseries, as does at least one association of ejidos (Chan, in press; Santos et al., in press; Arguelles et al., in press). Seed are sown in plastic bags filled with soil, and once harvesting is completed and the rains have begun (about June), seedlings are transplanted, usually into felling gaps, skid trails, and clearings where harvested logs are loaded onto trucks. Planting is done by ejido members. Sometimes, and in some ejidos, they have been paid for their labors, either through government programs or from earnings from timber sales; sometimes they plant seedlings as part of the community's unpaid labor requirement, referred to as ''fajinas'' (Santos et al., in press). Over time, in some ejidos, these practices have been modified and additional silvicultural practices have been added.

For example, although significant investments were being made each year in enrichment planting, these efforts were not evaluated until more than a decade had passed. Researchers working in collaboration with one of the ejido associations found that only about 5% of seedlings planted 2–5 years earlier had survived (Negreros-Castillo and Mize, 2003). Similar observations were made by foresters in one ejido, who visited planting sites 10–15 years later and found that the canopy had closed over former felling gaps and skid trails, and that mahogany seedlings planted there had either stagnated or died. However, they found that plantings in log yards 1/4–1 ha in size, previously cleared by bulldozers, had developed well, yielding high densities of fast-growing trees (Arguelles et al., in press). These observations of the success of mahogany planting on complete clearings were confirmed by experiments carried out by researchers to evaluate different silvicultural techniques for favoring regeneration (e.g., Snook and Negreros-Castillo, 2004). These insights led foresters to conclude that enrichment planting in felling gaps and skid trails was not a worthwhile investment. Instead, they decided to focus these efforts on log yards (although these represent only 1–3% of each annual harvest area) and shifting agricultural fields (although the latter are located outside the permanent forest reserves).

In general, the willingness of the ejidos of Quintana Roo to invest in silviculture has been favored by four principal interacting factors: formal institutions, including laws, regulations, government programs and agencies; the individual foresters who develop the management plans and silvicultural prescriptions, and organize the ejidos to carry out forestry activities; the support and involvement of donors and researchers from outside the region; and the interest of the ejido members, which varies depending on the economic importance of forestry in the ejido.

Since the forest law of 1986 provided the framework for communities/ejidos to make decisions and obtain the benefits from managing their timber resources, regulations have always required that licensed professional foresters provide technical services including developing and overseeing management plans, following the federal forestry regulations. These regulations call for enrichment planting to replace harvested trees. Expenses associated with carrying out management activities, for example inventories and silvicultural treatments, have always been paid by the ejidos, from forestry earnings, but government programs have, at various times, paid for the establishment of nurseries and replanting efforts (Santos et al., in press; Chan, in press; Arguelles et al., in press). For the first 6 years of community forestry in Quintana Roo, foresters who carried out and oversaw these activities were employed and paid by the federal government (Nolasco et al., in press; Santos et al., in press). The Forestry Law of 1992 reduced government involvement in forest management, leaving communities to pay the salaries of their foresters, which has represented a hardship for both communities and foresters, particularly where forestry earnings are relatively low (Santos et al., 1998; Arguelles et al., in press; Nolasco et al., in press). In 1997 the Federal Government established the Programa para el Desarrollo Forestal, or PRODEFOR, which provides co-financing, with state governments, for some natural forest management activities. In 2003, PRODEFOR invested the equivalent of US$ 568,414 in natural forest management in Quintana Roo (Nolasco et al., in press). Nonetheless, foresters consider that government support to forestry is insufficient to provide for optimal forest management, and is disproportionate to the importance of forestry activities in the state, accounting for less than 1% of the government support provided to agriculture and animal husbandry (Nolasco et al., in press; Santos et al., in press; Chan, in press).

The persistence and dedication of the individual foresters who develop and oversee the management plans for the Quintana Roo ejidos has contributed to convincing many ejidatarios of the importance of implementing silviculture, and to their obtaining funds to support these activities. To illustrate, the director of technical services for the largest forestry organization in the state, the Organizacion de Ejidos Productores

Forestales de la Zona Maya (OEPFZM), which manages a total of 214,150 ha of permanent forest reserve on 25 ejidos, has been working with this group since the organization was founded in 1986. Two of the other foresters who started out with this and the first forestry organization in the state (the Sociedad de Productores Forestales Ejidales de Quintana Roo, or SPFEQR), are still working to support ejido forestry, one directing forestry within the state government and the other running an independent forestry services office. The current director of technical services for the second largest, and first, forestry organization in the state, is the son of ejidatarios in one of the ejidos, who went on to obtain his forestry degree. These and many other foresters are personally committed to supporting the development of economically viable and sustainable forestry activities among the ejidos where they work. This reflects their own origins and loyalties and the outlook fostered by Mexico's forestry schools, a reflection of the fact that between 70 and 85% of Mexico's forests grow on communally owned lands.

International donors and researchers have also played a catalytic role in the development of community forest management in the region, beginning in 1984 with the so-called ''Pilot Forestry Plan'', supported in part by the German GTZ (Galletti, 1998; Richards, 1991; Kiernan and Freese, 1997). During the first 10 years of the process of organizing community forestry, foresters funded by the GTZ not only supported community organization, but provided training in inventory techniques and proposed an initial paradigm for silvicultural management (Flachsenberg and Galletti, 1998). Additional support was provided to the two first, and largest, organizations of ejidos (one of which originally included the ejido of Noh Bec) by several American foundations and Britain's DFID (Santos et al., in press).

Additional international funding was obtained by doctoral students from US and Canadian Universities, who initiated studies on various aspects of forestry in ejidos of the region (see Snook and Barrera de Jorgenson (1994), Dickinson and Whigham (1999), Dickinson et al. (2000) and Whigham et al. (1998)). Two who studied mahogany ecology and silviculture have sustained these efforts to the present time, with continued international financing, in collaboration with a few of the foresters and ejidos. Studies by international researchers have provided scientifically sound and statistically valid evaluations of silvicultural management initiatives and independent studies which have complemented and confirmed observations made by foresters. Crucial in this respect has been an active dissemination of research results, in Spanish, to foresters who write the management plans, ejidatarios who make the decisions about investments in silviculture, and representatives of government agencies who make and implement forestry regulations, through workshops, field visits to experiments and distribution in published form (Snook and Barrera de Jorgenson, 1994; Snook and López, 2004; Snook and Navarro, in press).

The foresters and ejidos of Quintana Roo still face significant challenges in achieving economically viable and sustainable silvicultural management, and some ejidos have advanced further in that regard than others. Ejidatarios have been willing to invest their communal labor, or ''fajinas'', in collecting seed, producing seedlings, and planting them in previously harvested areas because they consider such investments a way of benefiting their grandchildren, but ejidos with more valuable forests and higher earnings are more likely to consider making investments in silviculture. The ejido of Noh Bec, for example, which has advanced the most in silviculture, also earns the most from forestry activities: US$ 1 million a year, 50% of it from mahogany sales. Over 150 ejido members earn wages from forestry activities, and all ejido members obtain approximately US$ 1800/year in profit sharing (Arguelles et al., in press). Noh Bec has also benefited from the location of their forestry office in the state capital of Chetumal, and good connections, on the part of their forester (who was initially the lead field forester for the GTZ's ''Plan Piloto Forestal''), in the local, national and international arenas. As a result, they have obtained significant support from international donors and have been able to take full advantage of funding available through government programs. They have also developed a professional forest management team internal to the ejido, which has helped reduce costs and increase understanding of and interest in silviculture among ejidatarios (Arguelles et al., in press).

Other kinds of incentives have also fostered modifications and expansions in silvicultural management in the region. For example, since the establishment of PRODEFOR, government funding has supported the definition and protection of seed reserves in ejido forests. This funding has encouraged at least nine ejidos to establish such reserves (Santos et al., in press; Chan, in press; Francisco May Ek, personal commun.), while recent research has provided foundations for modifying existing guidelines for selecting these areas (Snook et al., 2005). An additional incentive for developing and implementing silvicultural management practices has been leverage provided by certification. Noh Bec and several other Quintana Roo ejidos are certified under the guidelines of the Forest Stewardship Council (FSC), although they are not exporting mahogany, and are thus not, as yet, obtaining financial benefits as a result (Santos et al., in press; Arguelles et al., in press; Nolasco et al., in press; Chan, in press).

6. Discussion

The studies presented above illustrate widely differing examples, in terms of geography, forest type and socio-economic context, of research on the adoption of silvicultural practices. They also vary in their methods and degree of analytical resolution, with Walters' pursuing detailed, local investigations at two sites in the Philippines, Sabogal and Almeida comparing a large number of sites across the Brazilian Amazon region, and Snook reviewing 20 years of experience with mahogany silviculture among dozens of ejidos managing community forests of different sizes in Quintana Roo, Mexico.

Differences aside, what these studies share is a pragmatic, interdisciplinary approach, which began with clear questions about why or why not silvicultural practices are being adopted by targeted users in particular cases. Guided by these questions, each of us sought to identify causal explanations for the relative adoption or non-adoption of silvicultural practices, striving in each case to minimize a priori biases about which explanatory factors are more or less likely to be important. In so doing, we were adhering to arguments put forth by Vayda (1996), Vayda and Walters (1999) and Vayda et al. (2004) with respect to not privileging particular factors in advance when seeking explanations for environmental or behavioral changes of interest. Ignoring disciplinary boundaries and conventions, each used diverse methods for obtaining data and considered a range of possible local and non-local/ ''macro'' influences in our explanations (Vayda, 1998, p. 578).

We used this approach because the adoption and spread of silvicultural practices in particular cases usually involves a complex series of causal events and situational factors that is not likely to be captured by a few factor variables or one theoretical model alone (c.f., Sunley, 1996). Findings from the three studies attest to this. Among other things, we learned that actual and prospective silviculture users are varied in knowledge, capacities and interests, and each of these can change over time (c.f., Johnson, 1972). How knowledge about novel practices is spread (e.g., technical outreach, inter-user knowledge sharing, imitation) was found to influence whether and what users know (Ryan and Gross, 1943; Boyd and Richerson, 1993; Pomp and Burger, 1995; Vayda et al., 2004). Even if prospective users know what to do and want to adopt, they may face constraints, which dissuade them from doing so or prevent them from doing so successfully. Such constraints were found to originate both locally (e.g., inadequate technical knowledge, lack of planting materials or land upon which to plant, unsuitable environmental conditions) and from the outside (e.g., market forces, hostile policies), as did incentives for adoption. In the end, the decision to adopt and successfully apply such practices (or not) reflects an interplay of these various influences.

Findings from the three studies provide evidence consistent to varying degrees with each of the major theoretical perspectives on rural innovations research outlined in Section 1. For example, ''indigenous'' and ''appropriate'' technology perspectives are supported by findings of widespread indigenous silvicultural practices in the Amazon. As well, the mangrove planting observed in the Philippines represents a well adapted and useful practice that initially emerged and spread without the influence of external agents. The ''straight transfer'' approach is likewise supported by findings that lack of knowledge was a constraint to wider adoption of silvicultural practices in Brazil, Mexico and, to a lesser extent, the Philippines (Vayda et al., 2004). Similarly, the importance of effective communication of research results to forest managers helped to explain successful silviculture practice among Quintana Roo ejidos (c.f., Nair et al., 1995:7).

Spatial and ecological influences of the kind frequently emphasized by geographers (e.g., Hagerstrand, 1967; Brown, 1981) were also found. Specifically, tree planting in the Philippines and Brazil was typically clumped in distribution and its historical spread was influenced by spatial variables such as the proximity to sources of information about planting and planting materials. In both Brazil and the Philippines, ecological factors pertaining to site suitability and pest/disease risk were also important determinants of silviculture success.

Silviculture adoption in Brazil and the Philippines was motivated, at least in part, by resource scarcities and associated market demands, or in the case of Quintana Roo, by a perceived threat of future scarcities, enhanced by certification and CITES listing of mahogany. As such, silviculture practice could also be seen in many cases as an ‘‘induced’’ innovation (e.g., Boserup, 1965; Walters, 2003; Mercer, 2004). Finally, government policies and structural/political factors (e.g., access to and tenure over land) were found in each of the three studies to have influenced the adoption of silvicultural practices, albeit in different ways and to different degrees.

That evidence was found that is consistent with each of the various theoretical perspectives further attests to the merits of the interdisciplinary approach advocated here. The discovery of these varied influences would have almost certainly been hindered had we gone into the field with strong biases reflecting any one or two particular theoretical perspectives and their associated methodologies. Policy-makers are faced every day with challenges that likewise do not readily adhere to traditional disciplinary perspectives. The concrete, policy-relevant findings described in the above three studies further speak for the advantages of using an interdisciplinary approach.

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