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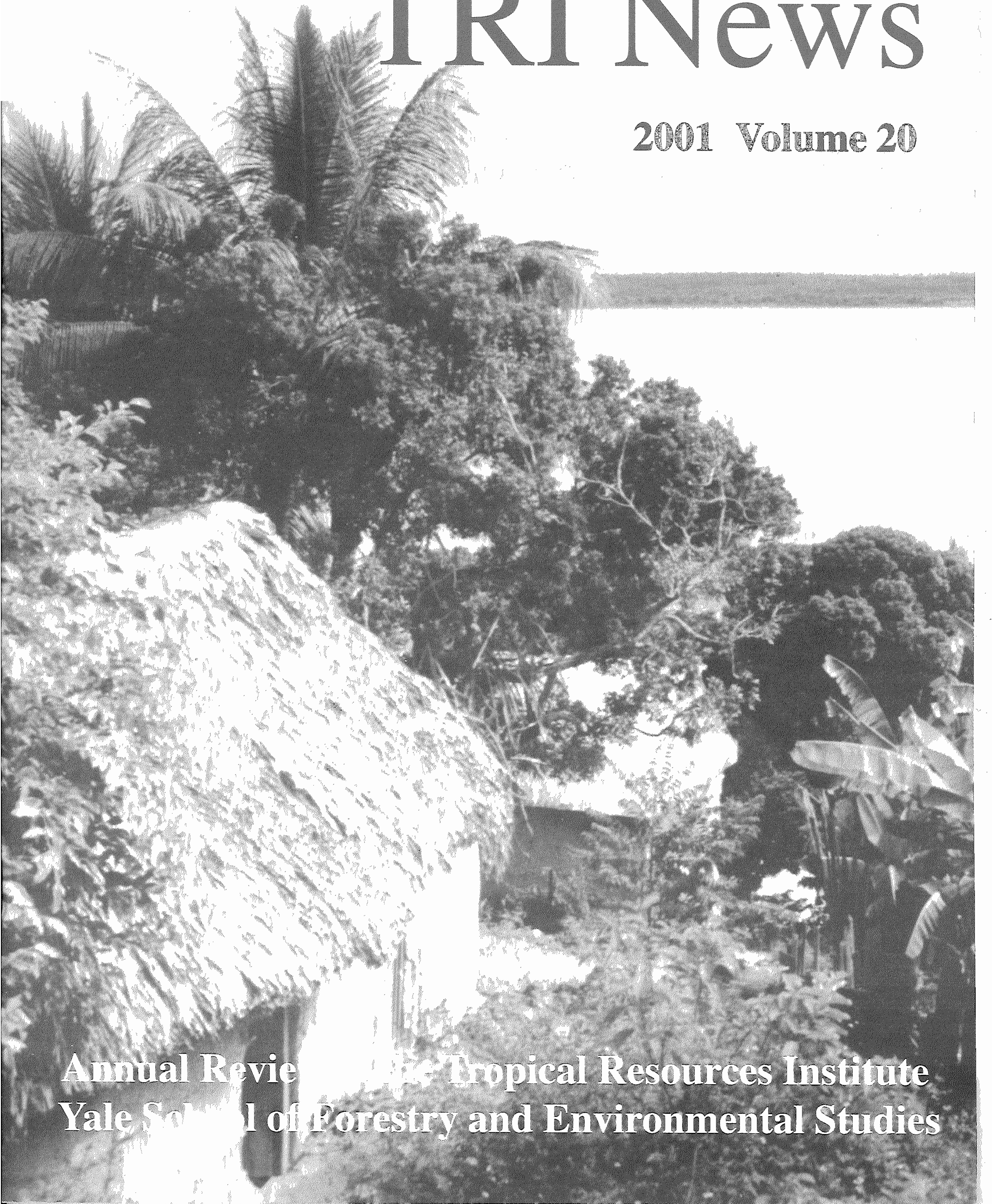
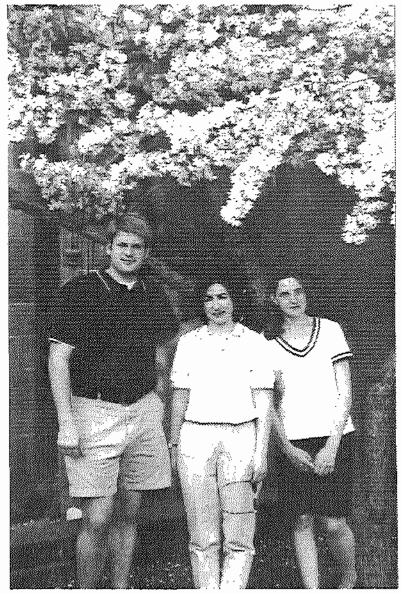


Annual Review of the Tropical Resources Institute
Yale School of Forestry and Environmental Studies

A Message from the TRI News Editors

The 20th issue of TRI News contains articles on a broad array of tropical research topics, ranging from the economics of water provision in Columbo, Sri Lanka, to carbon sequestration in Panamanian forest plantations. Each study in this volume tackles key environmental science and management questions; the results and conclusions herein provide critical insight on these issues and form an important foundation of case-studies for future projects in these areas. The editors of TRI News are proud to present this year's issue. We hope that the readership of this journal learns as much from reading these articles as we have gleaned from working with the contributing authors.

Enjoy,
Douglas, Rachel, and Sarah



TRI News Staff: Douglas Morton and Rachel Roth, Editors, and Sarah Osterhoudt, graphic design

A Message from the TRI Directors

The School of Forestry and Environmental Studies has been celebrating its centennial this year. When the School was founded, the forests of the United States were being harvested rapidly, carelessly, and wastefully, with little attention to their regeneration. "It had not dawned upon [the American people]", Gifford Pinchot wrote, "that timber can be cut without forest destruction, or that the forest can be made to produce crop after crop for the service of men." There were no professional forest managers in North America, and Pinchot, in founding the School, wanted to establish a skilled group of professional foresters in this country. In determining direction for the School, he realized it was important, then as now, to look at the needs of people living in forested communities, and not only the biophysical aspects of forests.

The threats to North American forests one hundred years ago were similar to worldwide environmental pressures today, and we still need skilled and insightful managers, trained in both social and biophysical considerations. Soon after its founding, the School began consideration of other forests of the world, and later of other environmental issues, while maintaining its fundamental belief in the importance of approaching natural resource management within its social and economic context. The studies in this edition of TRI News represent the broad range of interests in our School, reflecting the breadth of skills and approaches our graduates will take with them as professionals managing our world's resources.

We are fortunate that two new members of the faculty next year will be direct additions to the TRI team. Florencia Montagnini, a prior Director of TRI, will be returning to Yale after several years as Director of Silviculture and professor of ecology, tropical forest management, and conservation of biodiversity at CATIE (the Centro Agronómico Tropical de Investigación y Enseñanza), in Costa Rica. Her new insights, added to her knowledge of tropical ecology and forest management, will make her a valuable and central figure in our School's Tropical Resource program. Tropical ecologist Lisa Curran will also be joining the School next year from the University of Michigan, and has agreed to take over as Director of TRI. She brings a remarkable combination of ecological, social, economic and political insights to the consideration of forest management. We look forward to Florencia's and Lisa's insight and leadership in the Tropical Resources program.

James A. Bryan
Tropical Resources Institute Program Director

Mark S. Ashton
John Musser Director, Tropical Resources Institute

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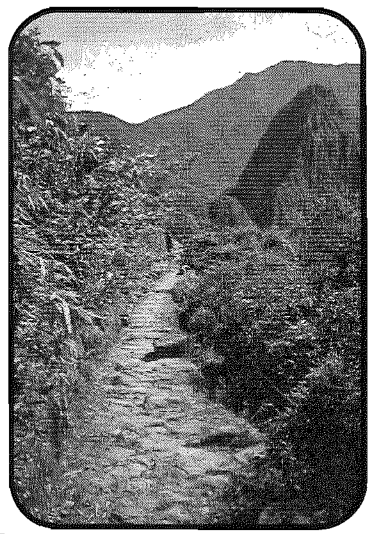
Monitoring the impacts of tourism along the Inca Trail to Machu Picchu, Peru

Gregory Jones, MEM 2001

Introduction

The Machu Picchu Historical Sanctuary (MPHS) in the Peruvian Andes has witnessed dramatic increases in visitor numbers in the 1990's, making it one of the most visited attractions in South America and an important source of tourist income for Peru. The two central attractions of the sanctuary are the citadel of Machu Picchu and the "Inca Trail" (See map), a 33-kilometer historic pathway leading to the citadel. Scenic, biological and archaeological attractions draw visitors to the sanctuary, but increasing numbers may now be threatening these resources. On the Inca Trail, for example, visitor numbers increased from 7,936 in 1990 to 74,896 in 1999, making it the most-used trekking route in South America (INC, 2000). However, despite the biological, cultural, and economic importance of the Inca Trail, no environmental impact monitoring has been completed along the trail to date.



The Inca Trail to Machu Picchu

Two institutions are presently responsible for the management of the sanctuary: the Peruvian National Institutes of Natural Resources (INRENA) and Culture (INC). Both are supported by an internationally-funded organization called Programa Machu Picchu (PMP). In early 1999, responding to the rising threat that tourism poses to sensitive high-altitude ecosystems in the sanctuary, PMP called for "Carrying Capacity" studies for both the trail and the Citadel. This research project was initiated in response to PMP's request. In the early stages of the project, the Limits of Acceptable Change (LAC) model for management of protected areas was selected as an appropriate study model for the Inca Trail based on literature review and discussions with local researchers. This study framework goes beyond traditional carrying capacity approaches, which are designed to manage protected areas by limiting visitor numbers, and addresses the management of use (amount, type, timing, location) to control specific biophysical and social impacts (Marion et al 1985). The LAC approach requires the use of specific, measurable indicators to evaluate environmental and social conditions; the specification of appropriate site-specific standards for these indicators; and a monitoring program to measure the indicators in order to define trends and to determine if standards are being met. Once this cycle is initiated, management will be able to identify problem areas and determine what management changes are needed to achieve the specified standard conditions (Stankey et al 1985).

This project was designed to help INC and INRENA begin to develop indicators and a social-environmental monitoring program. Thus, it included baseline studies of environmental conditions along the main trail, including conditions at campsites, as well as the use of questionnaires to evaluate visitor opinions on a wide variety of conditions along the trail and opionions on potential future management actions. In addition to the main trail, the project included surveys of other, less-used trails in the area as control sites. In this report I will present trends in some the social and environmental data collected, including a comparison of the main Inca Trail with less-used trails in the region, and discuss the implications of these data for the use of visitor limits and other management techniques to reduce environmental impacts along the Inca Trail.

Methods

The components of this project included:

- -- Selection of indicators;
- -- An environmental survey of the Inca Trail, campsites, and control sites;
- -- A social survey directed at trail users and tour guides; and
- -- Efforts to select standards for the social, ecological and aesthetic indicators that had been selected and measured.

The first stage of this project was the selection of indicators: specific social, environmental and aesthetic criteria. Indicators needed to be specific, reliable, repeatable, sensitive to tourism impacts, and cost-effective to measure. The chosen indicators (Table 1) were selected in consultation with PMP, based on a literature survey of indicators used successfully in similar situations (Crowder 1983, Stankey et al. 1990, Hollenhorst and Gardner 1994, Morin et al. 1997, UNSPS 1997). The categories of indicators (ecological, aesthetic, and social) were designed to correspond to the major objectives of the sanctuary, which include keeping ecosystems healthy, maintaining the beauty of the area, and satisfying visitors in order to maintain the area's tourism industry (INRENA and INC, 1999).

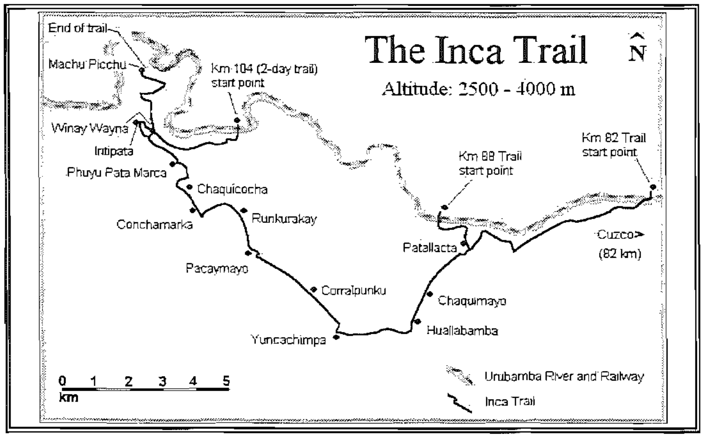
The second stage of this project was the environmental survey of trail and camp conditions along the Inca Trail, carried out during six site visits from May to August, 2000. The main Inca Trail route to Machu Picchu was surveyed along its entire length. Sites were 50m in length along the trail and were distributed at regular intervals, 285 m apart, in order to cover approximately 15% of the route with survey sites. Each set of sites was initiated by random selection of the location for the first site. Distances within each site were either paced or measured with a 50m measuring tape and distances between sites were paced. At each site, measurements for

Table 1: Examples of Aesthetic, Ecological, and Social Indicators

Aesthetic indicators	Ecological indicators	Social indicators
Number items garbage within defined areas at trail and camp study sites	Percentage of trees (10cm dbh or more) with physical damage along 50m trail study sites	Proportion of visitors unhappy with garbage along trails and in camp sites
Number and species of orchids along trail study sites	Number of eroding side trails along 50m trail study sites	Proportion of visitors unhappy with bathroom facilities
Width and depth of erosion rut along trail study sites	Number of exotic invasive species along trail study sites	Proportion of visitors who consider trail to be very crowded
Number of cases of vandalism and damage to Inca ruins at trail and camp study sites	Percentage vegetative ground cover within 20m buffer along trail and camp edges	Proportion of local residents experiencing negative conflicts with sanctuary management

indicator variables, as well as basic data (control variables) such as site elevation, GPS position, aspect and slope were recorded.

In addition to the main Inca Trail, four other Inca-built trails, three of which were within the Sanctuary of Machu Picchu, were studied using the same sampling procedure. This provided control sites for comparison with the heavily-used main trail, and it allowed us to map baseline environmental conditions for the less-used trails themselves, which will help to determine their suitability for heavier use in the future.



In addition to trail sites, all documented trail campsites were sampled. Campsites represent critical physical capacity bottlenecks and were found to be heavily impacted areas in my initial survey. Most campsites along the trail consist of terraces or platforms scattered in sloping terrain, linked by a trail network. For this study, each campsite was mapped, and areas of the various terraces were measured. Terraces of each campsite were numbered and randomly selected as survey site targets. Data recorded at each site included control variables and campsite condition indicators such as the number of side trails, number of pieces of garbage, proportion of camp area denuded of vegetation, and proportion of trees with signs of physical damage.

The third component of this project was a social survey along the Inca Trail, carried out through the use of questionnaires, as well as informal interviews with many visitors, guides, and INC and INRENA workers at stations along the trail. Questionnaires were administered for a total of ten days in June and July, 2000. The social survey was designed to complement and build upon the only existing major visitor survey to date (EFTEC 1999). The survey was administered at the last major camp along the route (Wiñay Wayna) and the adjacent camp at Intipata. Random members of each distinct group camping at Wiñay Wayna were asked to answer a questionnaire designed to help with the future management of the Inca Trail. An effort was made to avoid giving multiple questionnaires to a single group, since the responses would be biased towards similar answers. On each of the 10 evenings in which surveys were administered, a complete count of tents at Wiñay Wayna and Intipata were undertaken in order to provide an estimate of the number of people in the camp and thus the level of crowding that visitors were experiencing at the time of the survey.

The final component of this project was the effort to define standards for the social and environmental indicators being measured. This aspect of LAC requires value judgements on the part of park managers, and ideally should involve substantial participation of a wide range of stakeholders including government departments, local residents, representatives of the tourism industry in Cusco and Aguas Calientes, and knowledgable biologists and social scientists. Preliminary recommendations for possible standards for these indicators were discussed with the Chief of the sanctuary for INRENA. Input from several sources, including standards used in other protected areas (Stankey et al. 1990, USNPS 1997, Morin et al 1997) and specific stated objectives of the MPHS (INRENA and INC 1999) were used to support the selection of standards.

Results

Although the data may be most useful as a baseline for comparison with monitoring data in future years, they also allow for some immediate analyses. Comparisons of impact levels at trails and camps, impact levels along little-used "control" trails and the heavily used main trail, and visitor opinions of trail conditions on heavily crowded days and uncrowded days can help to prioritize areas of concern and develop management prescriptions.

In order to compare relative levels of impact along the trail and at camps, side trails are considered good indicators because they are areas of vegetation trampling, soil exposure and erosion, and increased littering. Table 2 shows that side trails at campsites tend to be more numerous and more heavily polluted than side trails along the main trail, although the lengths of side trails were similar in both cases.

Garbage is also an important indicator, since it represents a significant aesthetic impact. Amounts of trash along the trail and at campsites are highly variable depending on location, but average amounts are far higher at campsites (Figure 1 and Figure 2).

Ground cover along the sides of a trail is an indicator of the level of off-trail impact, but also varies significantly depending on the ecotype. The percentage of ground within 20m to each side of the trail that was covered with vegetation was quantified at each study site. Figure 3 shows that Inca Trail sites have lower levels of ground cover in five of six ecotypes as compared to control trail sites.

The effect of trail crowding on visitor satisfaction shows that the number of visitors does have some effect on visitor opinion, especially when they are asked to rate their satisfaction with campsites (Figure 4). Campsites tend to be areas of great concern along the Inca Trail, due to limited physical capacity, lower satisfaction rates and environmental and aesthetic impacts. But this analysis also shows that crowding in itself does not account for a large part of the variability in visitor satisfaction.

Visitors were also asked to indicate whether they would support various management actions in order to help remedy problems along the trail. Tourists generally responded very favorably to three trail management options that were presented:

- Build and maintain more bathroom facilities (79% agree or strongly agree)
- Limit the number of people allowed on the trail per day (69% agree or strongly agree)
- Restrict group sizes to a maximum of 15 (56% agree or strongly agree)

Table 2: Side trail (ST) impacts along the Inca Trail and at campsites

Site Location	Average # ST per study site	Average ST length (m)	Average # of pieces of waste
Main Trail, excluding camps	2.9 +/- 2.8	24.0 +/- 14.7	1.9 +/- 2.8
Main-trail campsites	10.5 +/- 6.1	26.7 +/- 16.5	8.5 +/- 6.9

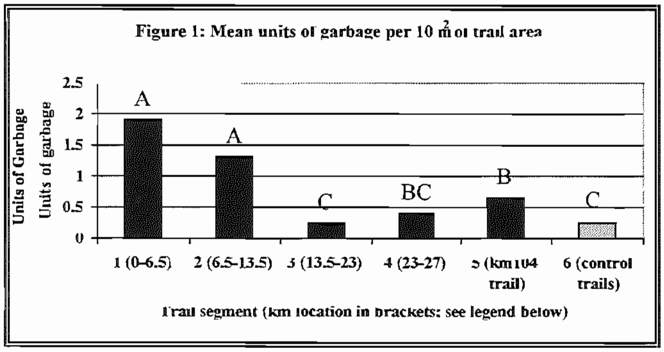


Figure 1: Mean units of garbage per 10 m² of trail area

Figure 1: Key: 1-4 are segments of the Main Inca Trail (see map): 1) From km 82 and km 88 (trail start points) to Huallabamba; 2) Huallabamba campsite to Pacaymayo campsite; 3) Pacaymayo campsite to Winay Wayna campsite; 4) Winay Wayna campsite to Machu Piccbu. 5) is the shorter "km 104" trail which is also heavily used, and 6) is an average of the four less-used control trails. Statistical ifferences at a 90% level of confidence are indicated where labels on the graph do not contain the same letter.

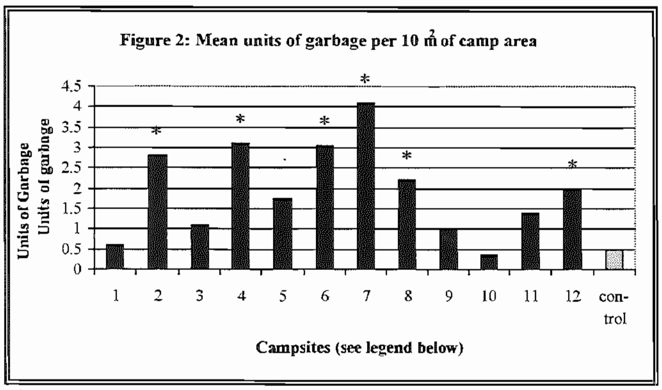


Figure 2: Mean units of garbage per 10 m² of camp area

Figure 2: Key to campsites: 1) Patalacta; 2) Chaquimayo; 3) Huallabamba; 4) Yuncachimpa 5) Corralpunka; 6) Pacaymayo; 7) Runkurakay; 8) Conchamarka; 9) Chaquicocha; 10) Phuyu pata marca; 11) Intipata; 12) Winay Wayna. The mean units of garbage per 10 m² at random sample sites in each campsite above. For comparison, the average of three campsites along the trail used little by tourists (approximately 1% number of visitors) have been used as control sites. Campsites labeled * have significantly higher amounts of garbage compared to the control sites at a 90% confidence level.

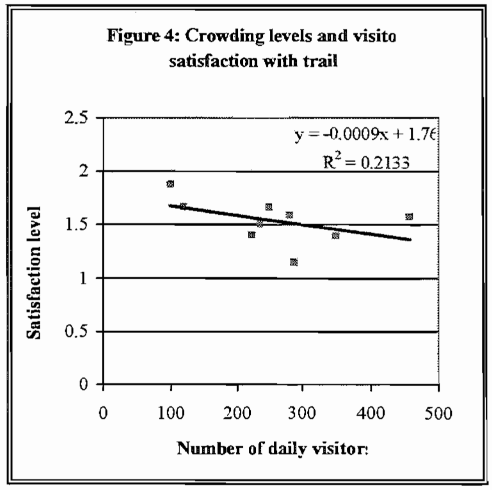


Figure 4: Crowding levels and visito satisfaction with trail

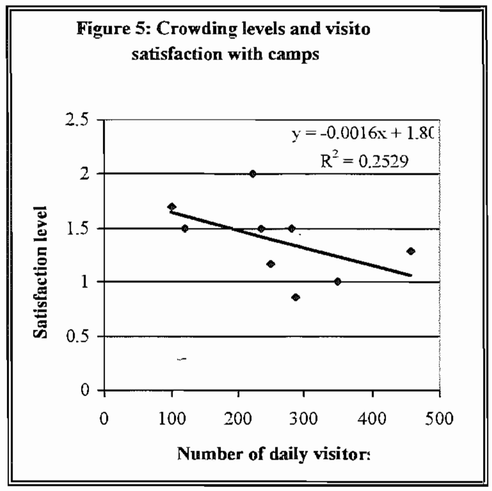


Figure 5: Crowding levels and visito satisfaction with camps

Figures 4 and 5: Visitor satisfaction with campsite and trail conditions relative to documented level of crowding at time of visit. Data points shown are mean responses at each level of crowding. A satisfaction level of 2 indicates "no problem with crowding", of 1 indicated "minor problems with crowding", and of 0 indicates "major problems with crowding."

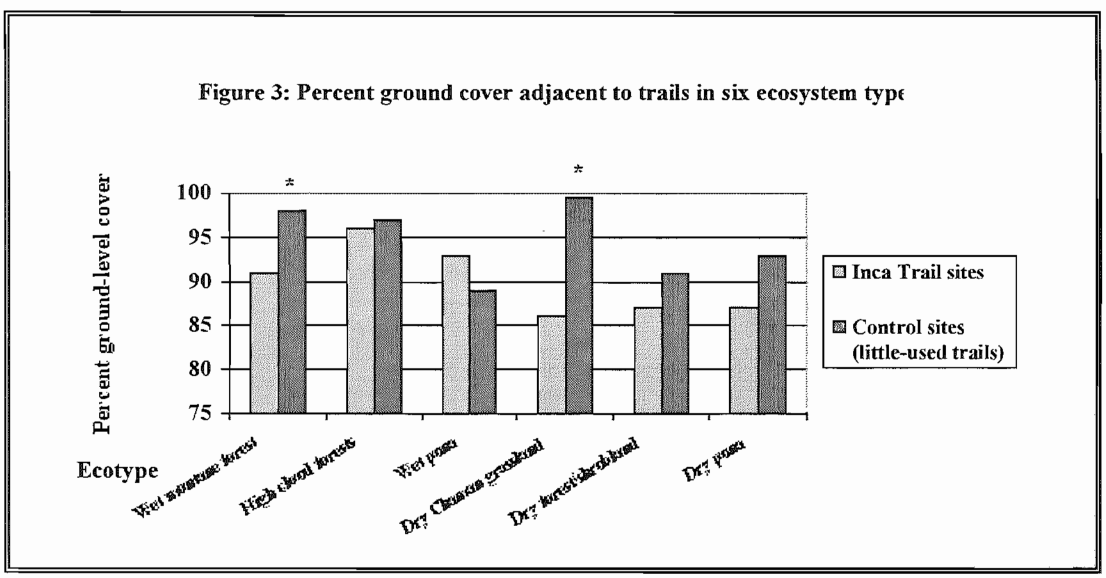


Figure 3: Percent ground cover adjacent to trails in six ecosystem type

Figure 3: The percent of ground covered by live vegetation within 20m of the trail is compared for each of six ecotypes (puna ecotypes are high-altitude grasslands). Sites along the main Inca Trail are compared with sites along little-used trails. T-tests at a 90% confidence level show that differences are statistically significant in wet montane forest and dry *Chaman* grasslands.

Discussion

Several trends are evident in the data collected. Firstly, impacts such as garbage and trampling of vegetative ground cover beside the trail are greater along the Inca Trail than along other trails in the MPHS that experience less tourist traffic. Increased number of people using a trail is associated with more garbage, a greater number of side trails, a wider section of the trail damaged by erosion, and more bare ground adjacent to the trail. However, in addition to differences observed between the main trail and lesser-used trails, there is significant variability between different sections of the main trail itself (for example, in the case of litter). Thus, visitor numbers alone are not sufficient to explain patterns of impact. Literature from other protected areas supports the notion that although visitor limits can represent a good option for trail regulation, the main factor affecting envionmental degradation and visitor satisfaction levels in protected areas is not the number of visitors but the behavior of the visitors (Marion et al 1985, Stankey et al 1985, Morin et al 1997). The implication is that options such as visitor education and enforcement of "pack it in, pack it out" regulations will be necessary on the Inca Trail in addition to limits on visitor numbers.

Secondly, the main problems along the main trail are associated with campsites, which represent the areas of greatest environmental impact and the greatest bottleneck in terms of physical capacity. Figures 4 and 5 illustrate that visitor satisfaction may be affected to some degree by crowding, especially visitor numbers at campsites, and visitors do support the implementation of daily limits. However, crowding is not the biggest issue on the Inca Trail; the top two concerns for tourists at present are trash and human waste, and the top management option in the visitor survey was to build and maintain appropriate bathroom facilities. Here again, it seems that the establishment of visitor limits must be supplemented with other management techniques.

In the future, analysis of social indicators such as visitor satisfaction, aesthetic indicators like solid waste and environmental indicators such as soil erosion will allow park managers to develop a better idea of the options that exist for park regulation, including options to minimize ecological impact by limiting visitor numbers or by reducing impacts of each visitor individually. Based on the preliminary analyses above, three options seem particularly viable to limit the impact *per visitor*: (1) Increased interpretive information and environmental education for visitors, residents, porters, and guides at the trailheads; (2) Stricter enforcement of regulations such as "pack it in, pack it out"; and (3) Construction and maintenance of better sanitary facilities in order to increase visitor satisfaction and reduce impact caused by defecation in inappropriate places around campsites.

Conclusions

In early 2001, sanctuary managers established a daily visitor limit of 500 trail users, began to place more emphasis on having visitors pack garbage out and required trail users to travel with guides, who will be responsible for promoting more environmentally-friendly use of the trail. Although these management actions will be helpful, trail managers will require better information in the future in order to establish appropriate long-term management prescriptions for a trail that will continue to be used heavily. My strongest recommendation is the initiation of a regular monitoring program based upon the types of social and environmental indicators measured in this study. Given the diversity of ecotypes along the trail, some sites can be expected to be more sensitive to environmental impact than others. Incorporated within a management planning and decision framework such as LAC, a monitoring program will allow managers to detect changes before impacts become severe or irreversible, identify trends, set appropriate visitor limits for the trail, and evaluate the effectiveness of trail management actions.

Acknowledgements

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References

Crowder, A. 1983. Impact indices based on introduced plant species and litter: A study of paths in St. Lawrence Islands National Park, Ontario, Canada. *Environmental Management* 7(4): 345-354.

EFTEC Ltd., London. 1999. La Sostenibilidad Economica y Financiera de la Gestion del Santuario Histórico de Machu Picchu. Documento de Asistencia Técnica No. 6, Programa Machu Picchu. 129pp.

Hollenhorst, H. and L. Gardner. 1994. The indicator approach to determining acceptable wilderness conditions. *Environmental Management* 18(6): 901-906.

Instituto Nacional de Cultura – INC. 1999. Visitor Statistics: Santuario Historico de Machupicchu.

Instituto Nacional de Recursos Naturales – INRENA and Instituto Nacional de Cultura – INC. 1999. Plan Maestro del Santuario Historico de Machupicchu.

Marion, J., D. Cole and D. Reynolds. 1985. Limits of Acceptable Change: A Framework for assessing carrying capacity. *Park Science* 6(1): 9-11.

Morin, S.L., S.A. Moore and W. Schmidt. 1997. Defining indicators and standards for recreation impacts in Nuyts Wilderness, Walpole-Nornalup National Ar, Western Australia. *CALMScience* 2(3): 247-266.

Stankey, G.H., S.F. McCool, and G.L. Stokes. 1990. Managing for appropriate wilderness conditions: The carrying capacity issue. Chapter 9 in: Hendee, J. C., R. C. Lucas and G.H. Stankey. 1990. Wilderness Management. second edition. Golden, CO: North American Press. 546 pp.

United States National Park Service (USNPS). 1997. The visitor experience and resource protection (VERP) framework: A handbook for planners and managers. NPS D-1215. Denver Service Center. Denver, Colorado. 103 pp.

The shadow price of improvements to water quality and reliability:
An application of contingent valuation analysis in Greater Colombo, Sri Lanka

Pradeep Kurukulasuriya, MESc 2001

Introduction

Over the last fifteen to twenty years, sustained economic growth in Sri Lanka has been paralleled by rapid urbanization, and the increasing needs of a growing industrial base . In particular, this has led to mounting pressures on the existing urban water supply system in Colombo, the largest city in the country. The lack of a 24-hour water supply in most parts of Greater Colombo, deteriorating water quality, and the absence of direct connections, and even any service at all in some parts of the city, are of escalating concern. There is little question, therefore, that additional investments in the urban water system are required. However, it is not clear which investment should have the highest priority and who should pay for it.

For example, should the water system concentrate on extending water service to more households? Should they focus more on providing direct hookups to more houses or providing standpipes for local communities? Alternatively, should the system instead focus on increasing the availability of water to those households that are already connected to it or on improving the quality of the water delivered? There is the additional issue of whether households that benefit from any improvements should bear the burden of the costs of the improved service provision or whether water should-continue to be subsidized by government. Who actually receives the subsidies when water has only a nominal fee?

This study cannot address all the questions above. However, it begins to shed light on the complicated and critical issue of urban water management by measuring what people in Colombo are willing to pay for both more reliable water service and better quality water. This information is useful for water planning because it measures the benefits of different investments in water services. Knowledge of household willingness to pay for system-wide improvements can indicate whether the benefits of increasing reliability and water quality are sufficient to justify the costs.The willingness to pay estimates can also inform the water utility to what extent consumers could pay for these improvements through additional water revenues (Whittington, 1991) and how much of the additional cost of an improved system would have to be borne by the government. Policy makers would then be able to assess whether (a) it is worthwhile investing public funds in such an endeavor; or (b) given the social context, an alternative method of improving household welfare should be pursued. The latter could, for example, entail extending coverage of the city's grid to a larger percentage of the population.

Investigating the factors that determine willingness to pay, such as socio-economic characteristics, household composition, and education, is important. Understanding who is willing to pay and how much reveals who will benefit from alternative policies. For example, if water subsidies are only provided for people with a direct connection, then the subsidies will not affect the poor because they do not have direct connections. Improving water quality could well benefit one group whereas improving reliability may benefit another. Furthermore, while several water valuation studies have been undertaken in the past, they have focused primarily on developed countries with limited application to other parts of the world.

Understanding the values associated with the provision of water supply in developing countries is important for designing more effective development policies. Previous contingent valuation (CV) studies have examined a number of important methodological issues such as the temporal dimensions of willingness to pay valuations or payments, procedures used to elicit willingness to pay, consistency in the values of willingness to pay over time (Loomis, 1989) and giving respondents time to think (Whittington et al, 1992). However, more basic policy issues for developing countries have often been overlooked. The role of public taps, people will pay for more reliability, and what they will pay for better quality water need further examination. This study begins to address these issues by examining willingness to pay in Colombo, Sri Lanka,

Research Method

In this study, willingness to pay (WTP) was estimated by the contingent valuation (CV) method, a technique often used for the valuation of non-market goods and services. This is a direct method of estimating values by asking a sample population about their willingness to pay for a hypothetical good or service. The method has received widespread attention in the economics literature (e.g. Cameron, 1987; Whittington, 1992; IUCN, 1999, World Bank, 1999) and has been applied in a variety of contexts. In-depth one-on-one interviews of the heads of 150 households were conducted (between June and August, 2000 in the Greater Colombo area) to determine how much respondents were willing to pay in excess of their current monthly water bills for improvements in provision/service.

The improvements in service were defined in terms of (a) reliability improvements in supply—i.e. increasing the number of hours of water availability to 24 hours, and (b) quality improvements—i.e. to a level where pre-treatment of water would not be necessary. As the households chosen for the interview had to have a private metered connection, it was explained to respondents that the additional payment would be made in the form of a surcharge on monthly water bills.

Given the well-known inherent weaknesses of contingent valuation, the method to elicit willingness to pay values was crucial. The results presented in this paper are based on the responses to the bids of a "sequential bidding game" carried out during the interview. Box 1 illustrates the bidding game in the form of a flow chart. As indicated, respondents were asked whether or not they would pay a specified initial sum (bid 1—which was varied across the sample) and depending on the response, a higher (bid 2H) or lower (bid 2L) amount was then asked and the game continued. In total, three bidding levels were utilized (refer to Whittington, 1991 for more detail on bidding games). The bids placed before respondents were based on percentage increments of the current tariff structure that were determined through pre-testing of 25 households prior to the actual survey. Two separate games were carried out for reliability and quality improvements respectively.

The hypothesis was that improvements in reliability and quality were not equally important to the population and therefore warranted separate examination of respondents' willingness to pay. An assumption was made here that individuals are able to distinguish between the benefits they would receive from these two types of improvements, although some have argued that this may not be possibel given that improvements in reliability inherently improve quality as well. The elicitation procedure also included a final question (following the bidding game) on the maximum respondents were willing to pay for improvements in reliability and quality, respectively. Respondents were told that they could name any amount they considered to reflect their true willingness to pay for the improvements that were described (including zero values).

The survey also investigated the extent and use of water in daily household activities, and in particular, respondents' perceptions of the quality and reliability of the service they were receiving. Other basic data on household and socio-economic characteristics, including household composition and size, age, education and employment status of household members, characteristics of the homes (number of rooms, type of home-- multi-story, basic or shanty). Income and proxies for income (such as whether they owned a motor vehicle and what type) were also collected.

The conceptual framework underlying the empirical analysis conducted in this study has been well established in the economic literature (see Whittington, 1992 et al.; Cameron, 1994; 1997; World Bank 1999). Let V(Y,P,N,Q) represent an individual's indirect utility function, with monetary income (Y), the prices of other goods and services (P) and other demographic and economic factors that might influence the household's ability to pay or constrain its behavior, (N). Q represents the commodity of interest (in this case, the proposed improvement in reliability and quality of water in the existing water system), which is also an exogenous factor that influences each person's decision in maximizing his/her utility. Thus,

$$V(Y_0 - WTP, P_0, N_0, Q_1) = V(Y_0, P_0, N_0, Q_0) \text{--}(1)$$

defines an individual's willingness to pay for changes in the water system, Q, from Q_0 to Q_1 (Whittington et al, 1992). From equation (1), it can be inferred that an individual's willingness to pay for improvements in the water system is a function of the following variables (determined by consumer demand theory):

$$\text{Willingness to pay (WTP)} = f(Q_0, Y_0, P_0, N_0) \text{ --}(2)$$

where: Y = income;

P = price of all substitute goods and services;

N = demographic and economic factors that will inflence individual's ability to pay. This includes the time available for household members to obtain water from traditional sources, measures of non-monetary income/wealth, household characteristics that would influence water needs, attitude variables and so on;

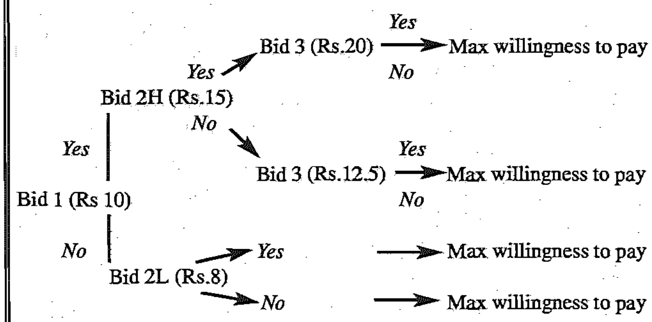
Q = character of the good being valued (also an exogenous factor influencing a person's ability to pay).

The regression equation estimated was assumed to be linear:

$$WTP = \beta_0 + \beta_1\mathbf{X} + \beta_2\mathbf{Z} + \beta_3\mathbf{Q} \text{ ----- }(3)$$

where **X**, **Z** and **Q** are vectors denoting socio-economic characteristics, prices and characteristics of the good (i.e. type of improvement in the water system) respectively, and βs are the coefficients to be estimated.

Box 1: Flow Chart of Sequential Bidding Game



Note: The bids indicated above are for illustrative purposes only. The actual bids used in the Colombo survey were based on the tariff structure that is currently used for billing customers and were varied across the sample. Two bidding games were also conducted to elicit the willingness to pay for reliability and quality improvements, respectively.

Results

Analysis of the household data indicated that 65.3% of respondents where male and 63.76% were under the age of 45 years (Table 1a). The average age of female respondents was 38 years. The sample population was literate, with more than 67% with 1-12 years of schooling while 25% had both a secondary and higher education. Of women respondents, 97.87% had at least secondary education, 23% of which had a university education (Tabel 1b). In terms of employment status (Table 1c), 62% of all respondents indicated that they were engaged in a skilled profession (defined as one which required at least a secondary education or higher to secure employment), while 16% were homemakers. A few respondents were still completing higher education, but were considered as the heads of households as they were the main income earners. Of those respondents who were involved in homecare, the majority were women (88%), with an average age of 43 years (std. dev. of 11.6).

The average income per household was approximately Sri Lankan Rupees (LKR.) 15,716.67 (std. dev.)

Table 1a: Sex and Age of Respondents

	Frequency	Percentage
by sex		
Male	98	65.33
Female	52	34.67
by age		
14-25 yrs	21	14.09
26-35 years	42	28.19
36-45 years	32	21.48
46-55 years	27	18.12
55 and above	27	18.12

Table 1b: Education

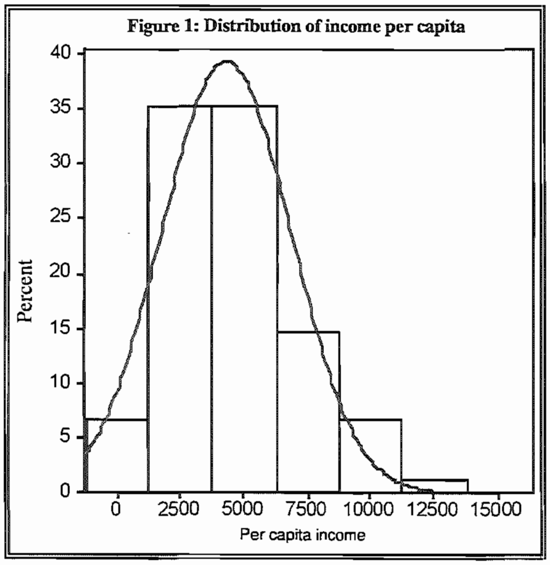
	Frequency	Percentage
No Schooling	2	1.43
Primary and Secondary	95	67.86
Vocational Training	8	5.71
Higher education (University)	35	25.00

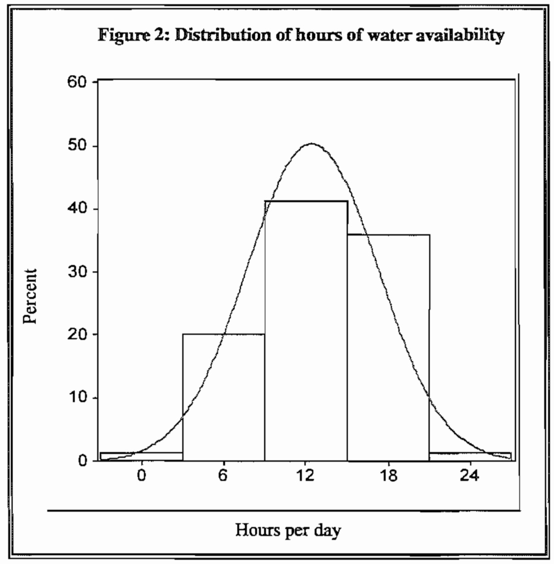
Table 1c: Employment Status of Respondents

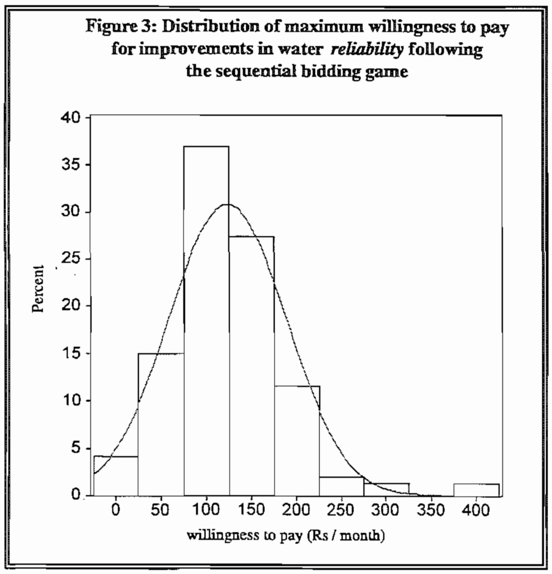
	Frequency	Percentage
Skilled	93	62.42
Unskilled (manual labor)	13	8.72
Homecare	25	16.78
Part time	10	6.71
Unemployed	8	5.37

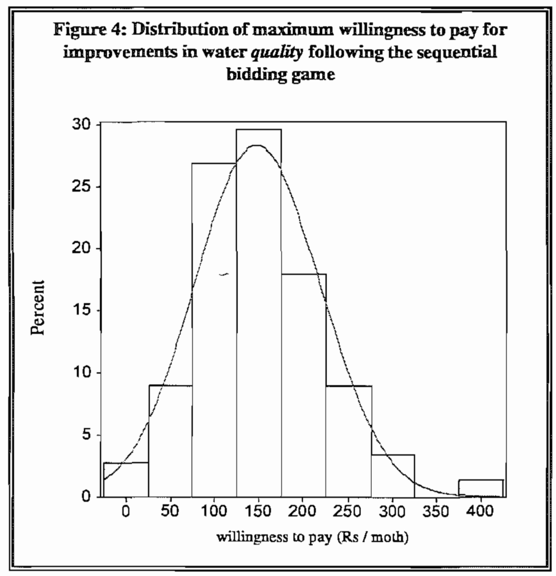
Table 1d: Hours of Water Supply

	Number of households	Frequency
< 6 hours	24	16.00
7-12 hours	61	40.67
13-18 hours	60	40.00
18-24 hours	5	3.38









8326.08) per month, or approximately US$ 196.50. In terms of per capita income, this amounted to an average of LKR.4293.35 per person per month (std. dev. 2540.20) or US$636 per year (Figure 1). Although lower than other estimates that have been made, it compares somewhat favorably to the average annual income per capita estimated by the Government of Sri Lanka of US$750, and of US$810 by the World Bank (1998 estimate).

Examination of household responses on the reliability of water supply indicated that the average number of hours of availability is less than 12 hours per day (Table 1d and Figure 2). Further, 36% of respondents stated their water pressure was poor, while 52% reported it was average. Importantly, nearly 60% confirmed that they stored water in order to ensure a continuous daily supply to their homes.

Regarding quality issues, 53% of respondents indicated that at times the water was discolored. An overwhelming majority found the taste of water to be satisfactory. Interestingly, 44% of respondents indicated that the water was safe to drink without treatment, and another 46% concurred that this was true at least on some days. However, nearly all respondents indicated that pretreatment of water is carried out (generally boiling) prior to consumption in their households.

The analysis of the open-ended questions (that followed the sequential bidding game) indicated that the maximum willingness to pay of respondents for improvements in reliability and quality respectively was approximately twice the amount that they currently incurred in monthly water bills. This amounted to a monthly payment of LKR.124 (std. dev.64.7), and LKR.147 (std.dev.70.3) for improvements in reliability and quality, respectively. The distributions of the payments are depicted in figures 3 and 4. In terms of average per unit cost, the payments were approximately LKR.4.59 per unit for reliability improvements, and LKR.5.44 per units for quality improvements. Currently, households spend, on average, LKR. 4.96 per unit cost of water each month to receive water to their homes. These results compare closely with other studies that have examined water reliability issues in South Asia. For example, a World Bank paper on urban water use in India found that willingness to pay for improvements in supply (primarily in terms of reliability) were slightly more than double the prevailing water charges (World Bank, 1999).

Analysis of the survey bids by income quintiles (Table 2) reveals that the willingness to pay for improvements in quality and reliability range varies across incomes groups. The lowest quintile group is only willing to pay an additional LKR.106 for reliability, and LKR.121 more for quality improvements. In contrast, the highest income group is willing to pay LKR.172 more for reliability, and LKR.193 more for quality, improvements. That is, given that the current average water bill is approximately LKR. 134, the lowest income group is willing to pay an extra 79% for reliability and an extra 90% for quality. In contrast, the more wealthy households were willing to pay an extra 128% for reliability and an extra 144% for quality. These results demonstrate that while the desire for improvements to the current system transcends income differences, the higher income users are willing to pay more than the lower income users so they will benefit more from any uniform improvement in service.

Table 2: Willingness to pay by Income Quintiles*

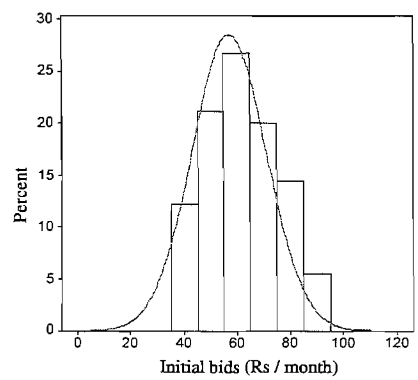
Income Quintiles	Mean WTP bid for ***reliability*** improvements	Mean WTP bid for ***quality*** improvements
1 (lowest)	106.00	121.429
2	118.65	136.786
3	106.04	136.897
4	134.04	141.500
5 (highest)	172.40	192.931

**Includes all bids where respondents indicated that they would not pay any additional amount to what is currently paid*

The results confirm that improvements to water quality are desired more than improvements in reliability. Informal discussions during the survey revealed that water unavailability was less significant an issue compared to quality given that many households had storage facilities, and could therefore avoid much of the inconvenience caused by water shortages. However, the deterioration of water quality necessitated additional "coping costs" to households attempting to safeguard health, including the cost of energy and time spent for boiling.

In order to understand the distribution of bids for quality and reliability, an analysis was undertaken to examine how different factors influenced those bids. A statistical analysis of the discrete choice responses to the "closed-ended" questions of the sequential bidding game was then conducted.. Figure 5 illustrates the distribution of initial bids to which respondents indicated that they would be willing to pay for improvements in reliability. A discrete choice model based on a maximum likelihood estimation procedure for analyzing closed ended contingent evaluation surveys was used for the economic analysis.. The method estimates a nonlinear regression explaining how different independent variables influenced the choice to make the proposed payment or not.

Figure 5: Distribution of Initial Bids in Sequential bidding game to which the respondents indicated they were willing to pay for improvements in reliability



From Table 3, it is apparent that willingness to pay for reliability improvements are positively associated with income per capita and households with children under 18 years of age. As expected, willingness to pay was inversely related to the number of hours of supply (PCONHRS) and respondents' assessment of water pressure. Thus, for example, as supply availability increases by 1 hour, the willingness to pay is reduced by LKR.1.50. It is also evident that for every LKR. 1000 increase in per capita income (YPER-

Table 3: Maximum Likelihood Estimates based on Closed Ended Contingent Valuation Analysis (Cameron and James, 1989) for willingness to pay for improvements in water *reliability* only

Parameter	*Description*	*Estimate*	*Approx Std Err*
INTERCEPT	Intercept	93.55	23.5
YPERCAPITA	Income per capita	0.005	0.002
D_CHILDUNDER18YRS	Dummy for households with children between 5-18 years of age, inclusive	14.85	8.68
D_INFANTSINHH	Dummy for households with infants (less than 5 years of age)	-23.09	11.27
PCONHRS	Number of hours of supply available	-1.50	0.97
CURRENTPRESSURE	Respondents's assessment of water pressure (scale of 1-3 where 1=poor)	-10.95	7.04
D_STORAGE	Dummy for households that store water (1=store)	-18.31	9.97

CAPITA), the willingness to pay for reliability increases by LKR. 5.00.However, if the magnitude of the coefficients is an indication of the relative importance of a particular variable, then it appears that variables such as, households with children (D_CHILDUNDER18YRS), poor water pressure (CURRENTPRESSURE), and whether or not households store water (D_STORAGE), have a large influence on willingness to pay values. Interestingly, households that currently store water are willing to pay LKR.12.96 less for reliability improvements than those that do not. This is because households with storage capacity are less likely to be inconvenienced by interruptions of water service compared to those that do not have storage capacity.

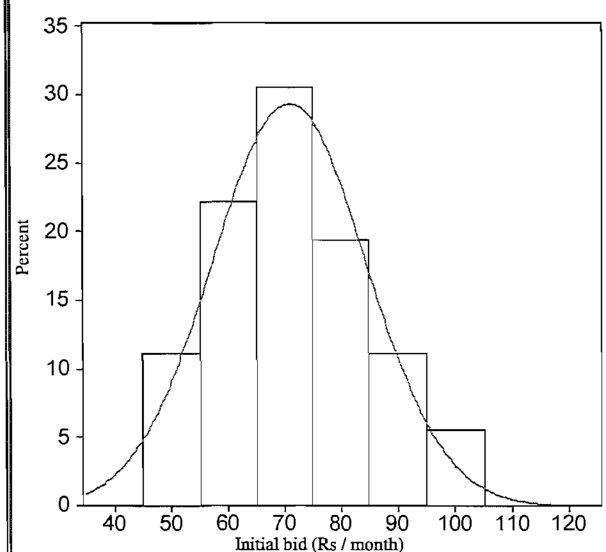
Table 4: Maximum Likelihood Estimates based on Closed Ended Contingent Valuation Analysis (Cameron and James, 1989) for willingness to pay for improved water *quality* only

Parameter	*Description*	*Estimate***	*Approx. Std Err*
INTERCEPT	Intercept	57.92	7.24
D_PRESSURE	Dummy variable for pressure (1=poor, 0=otherwise)	23.14	8.27
D_STORAGE	Dummy variable for households that store water (1=store)	-12.71	6.54
D_LARGEHOUSES	Dummy variable for large homes (1=more than 1 floor)	33.4	9.98
D_HRISK	Dummy variable for respondents perception of health risks when drinking water without boiling (1=very high)	15.82	7.01

*** all values are significant at the 10% level*

Examination of respondents' bids for water quality improvements (Figure 6) highlighted the influence of a different set of variables (Table 4). As expected, willingness to pay for quality improvements were positively influenced by respondents perception of (a) the health risks associated with drinking untreated water (D_HRISK) and (b) poor water pressure (treated here as a dummy variable, D_PRESSURE). Surprisingly, the impact of income variables , including household income and income per capita, did not appear to be statistically significant in any of the models for willingness to pay for improvements in water quality. Various forms of the income variable were tested (log, quadratic etc.) but with little success. The variable D_LARGEHOUSES, which indicated the number of floors in each respondent's home is treated as a proxy for household wealth. Although just a proxy, (R^2=0.45 between income per capita and the proxy variable), it was more effective than several other variables explored (including vehicle type, vehicle value, type of flooring). From the proxy variable, we estimate that the willingness to pay of wealthier households (i.e. homes with more than one floor) was approximately LKR.34.00 higher than all other households (basic 1-floor homes). Interestingly, households that stored water indicated a lower willingness to pay for quality improvements than households that did not.

Figure 6: Distribution of Initial Bids in Sequential bidding game to which respondents indicated willingness to pay (Rs.) for improvements in quality

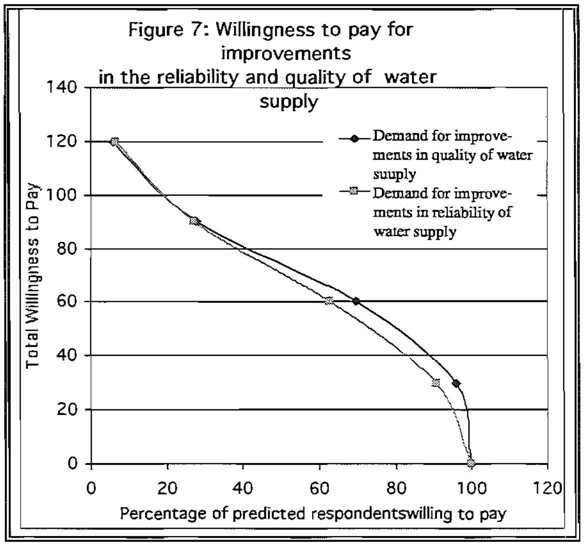


Conclusion

Based on the above willingness to pay values, an estimate of the total value of the welfare change for the population from which the sample is drawn can be obtained by multiplying the sample mean by the total population (Freeman, 1992). In this case, given that there are 502,416 households with direct water connections, the total value of the welfare change from improvements to water reliability would be LKR.62,299,584 per month or US$ 9,117,012.29 per year. In contrast, the total value of the welfare change from improvements to water quality is a slightly higher sum of US$10,808,071.02 per year.

The results of of the above regression analysis were also used to obtain willingness to pay functions for improvements in reliability and quality (Figure 7). The functions derived using the maximum likelihood coefficients of the estimated models in Table 3 and 4, are in effect, the inverse demand functions for a given change in the system (i.e. improvement in reliability and quality of water). As evident in figure 7, there are substantial benefits in terms of consumer surplus to be obtained from making improvements to the quality and reliability of urban water supply.

An important policy conclusion that can be drawn from the above results is that, on the basis of willingness to pay of respondents and other survey data, there are clear shortcomings in the existing water supply system. The results of this study indicate that households with private/direct connections to the city's water grid were prepared to spend an addition of 0.8% of average annual household income on water bills in exchange for improvements in reliabil-



ity and 0.9% of average annual household income for improvements in the quality of water. Knowledge of the willingness to pay of this particular subgroup of water consumers should in turn serve as a benchmark against which the local water utility/government could assess various options for making the requisite improvements (including technology and/or pricing revisions to meet the costs of improving the system). Clearly, there are welfare gains to be obtained if these improvements are made given that the cost of doing so is relatively inexpensive—e.g. maintenance of pipes, better treatment. However, the exact net benefits need to account for the marginal cost of improving the service.

There remains, however, scope for improvement of the above results on both a policy as well as methodological level. On a policy level, this paper focused only on one type of water user in Colombo. A more comprehensive account of the welfare implications of improving the current water system needs to take into account other users also, including those who rely on public standposts (communal taps) and the marginalized households that lack access to either a direct or communal supply. Furthermore, one immediate concern from the above results is that the willingness to pay for quality and reliability improvements appear to be highly correlated. This raises the question of whether respondents were in fact indicating their true willingness to pay for each of the specific types of improvements. On the other hand, from a methodological perspective, more rigorous analysis of the willingness to pay from the bidding game can also be undertaken.

The above concerns are the focus of ongoing research. The above results are being crosschecked against various other techniques (including interval analysis using maximum likelihood estimation, probit and logit procedures) to obtain consistent estimators of the willingness to pay functions. Furthermore, willingness to pay for improvements in quality and reliability is being estimated with the use of a split sample, where one group is asked for willingness to pay for improvements in quality, while the other is asked to value improvements to reliability in supply.

Acknowledgements

Field research for this project was conducted during the summer of 2000 with financial assistance from the Tropical Research Institute (Yale University), Economy and Environment Program for South East Asia (EEPSEA, Singapore), and the Munasinghe Institute of Development (Sri Lanka). I would like to thank Prof. Rob Mendelsohn, my project advisor (Yale University's School of Forestry and Environmental Studies), Prof. Mohan Munasinghe (World Bank), Prof. Dale Whittington (University of North Carolina) and Prof. Hilary Sigman (Yale University) for their recommendations. We are also indebted to Olaf Kuegler, (School of Forestry, Yale University), Ihsan Ajwad (World Bank), Dominika Dziegielewska and Shane Rosenthal (School of Forestry and Environment, Yale University), Sharmila Basnayake (Columbia University), Michel Woodard (Yale University) and Tharanga Fernando (MIND, Sri Lanka) for their suggestions and advice at various stages of the study. We take all responsibility for any remaining errors.

Please note: This paper is based on the initial results of a larger study. It should be noted that the results presented in this paper are therefore not final, but indicative of the general trend that has energed in the course of the initial analysis.

References

Cameron, T.A and Englin, J (1997) Respondent experience and contingent valuation of environmental goods, *Journal of Environmental Economics and Management*, 33: 296-313.

Cameron, T.A and James, M.C (1987) Efficient estimation methods for "closed ended" contingent valuation surveys, *Review of Economics and Statistics*, 269-276.

Cameron, T.A and Quiggin, J (1994) Estimating using contingent valuation data from a "dichotomous choice with follow-up" Questionnaire, *Journal of Environmental Economics and Management*, 27, 218-234.

Loomis, J et al (1996) Improving validity experiments of contingent valuation methods: results of efforts to reduce the disparity of hypothetical and actual willingness to pay. *Land Economics*, 72: 450-61

Whittington, D et al (1990) Estimating the willingness to pay for water services in developing countries: A case study of the use of contingent valuation surveys in Southern Haiti, *Journal of Economic Development and Cultural Change*, 292-311.

Whittington, D et al (1992) Giving respondents time to think in contingent valuation studies: A developing country application, *Journal of Environmental Economics and Management*, 22: 205-225.

Young, R (1996) Measuring economic benefits for water investments and policies, World Bank Publication.

World Bank (1999) Willingness to pay but unwilling to charge: Do willingness to pay studies make a difference, UNDP-World Bank Water and Sanitation Program, South Asia.

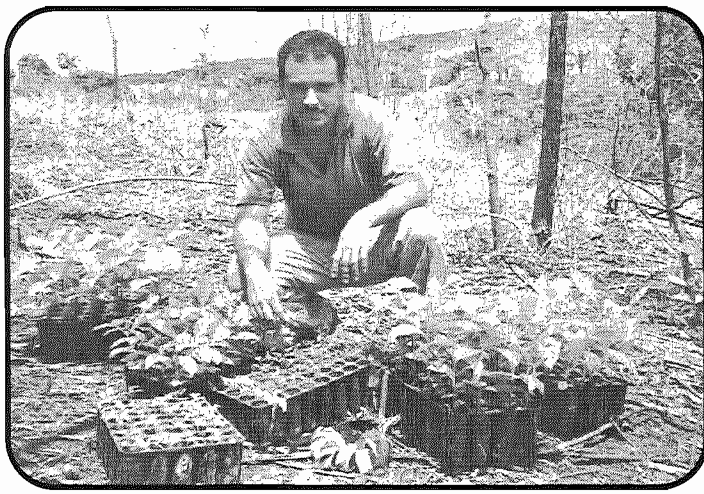
TRI launches collaborative research and education project in Panama

Mark Wishnie, MFS 2001,
Adriana Sautu, and Jose Deago

Project Background

On January 2, 2001, Yale University's Tropical Resources Institute (TRI), Harvard University's Center for International Development (CID), and the Smithsonian Tropical Research Institute's Center for Tropical Forest Science (CTFS) initiated the Panama Native Species Reforestation Project (PRORENA), a research and education project involving nearly a dozen local Panamanian collaborators. The project is intended to address the under-utilization of native species in neotropical reforestation projects, and to provide unique research and training opportunities for Latin and North American university students.

The project is sited in Panama for several reasons. In Panama, as in much of the tropics, an expanding agro-pastoral frontier, unsustainable timber harvests, and the low economic value accorded to natural forests and forest plantations are driving tropical deforestation. Between 1947 and 1992 Panamanian forests were reduced by more than 30%, and continue to decline at an estimated rate of 17,000 hectares per year (Romero et al. 1999). This large-scale forestland conversion is associated with increasing rates of erosion, declining soil and water quality, and growing demands of urbanizing lowlands for both the agro-pastoral products and the watershed services supplied by upland areas. Issues of forestland conversion and watershed services are given special urgency in Panama by the central importance of the Panama Canal and its watershed to the country's domestic economy and to world trade.



Jose Deago planting seedlings.

Although recent Panamanian legislation, such as a program to provide tax incentives for reforestation ventures, are indicative of a growing interest in reforestation, 93% of plantations established in 1999 were planted in one of four exotic species: teak (*Tectonia grandis*), African mahogany (*Khaya senegalensis*), Caribbean pine (*Pinus caribaea*), and *Acacia mangium* (Romero et al. 1999). Exotic species tend to be favored because their management is well understood, well-developed markets exist for their products, and improved seeds are readily available. For these reasons, these same four species are planted widely throughout the tropics. Native species tend not to be favored because the management of most species has been little studied, developed markets exist for only three or four species, and seeds are often difficult to obtain. This dis proportionate reliance on exotic species, common to both commercially and ecologically motivated reforestation efforts, has led to the establishment of forests that are able to provide only a limited range of the social, ecological, and economic services that may be derived from forested landscapes.

While it is clear that sufficient silvicultural information is lacking for most Panamanian native tree species, even a brief survey reveals that a significant amount of information does exist for some species. However, much of the existing information is dispersed among various scientific publications, agency reports, and university theses and dissertations, and is published in a variety of languages, including German, English, Portuguese and Spanish. Further, a dozen or more projects reforesting with native species for conservation, timber production, or other purposes already exist in Panama. Unfortunately, these projects generally do not have the resources to collect and analyze data or publish the results of their work. Many people concerned with or involved in native species reforestation are unaware that other, similar projects exist. As a result, much valuable information and experience that might serve to inform and improve native species management is lost.

However, Panama presents a unique opportunity to develop viable alternatives for addressing these problems in Latin America. Located at the juncture of Central and South America, Panama is home to an impressive diversity of flora and fauna. Though host to significant populations of rural poor and subject to chronically high rates of deforestation, Panama is also home to the Smithsonian Tropical Research Institute (STRI), the Center For Tropical Forest Science (CTFS) the long-term 50 ha research plot at Barro Colorado Island, universities with strong botany programs and a new forestry program, and an extensive network of protected areas administered by the National Environmental Authority (ANAM). Together these resources offer a substantial baseline of ecological information and a strong network of logistical support and infrastructure upon which to build a successful program.

PRORENA seeks to develop reforestation strategies for degraded Panamanian landscapes utilizing native species of tree, and to train forest resource professionals with the skills and knowledge necessary to bring these efforts to fruition. PRORENA's activities involve active collaboration with private partners (Ecoforest-Panama S.A., Futuro Forestal S.A., individual private landowners), public partners (the University of Panama, the Panama Canal Authority, the National Environmental Authority, the Center for Sustainable Development), and community organizations (the Association of Independent Producers of Darien).

PRORENA's Mission

PRORENA's mission is served by four objectives:

-- To serve as a coordinating and technical advisory body for native species reforestation efforts, and to disseminate relevant silvicultural, ecological, social, and economic information to interested parties throughout Panama.

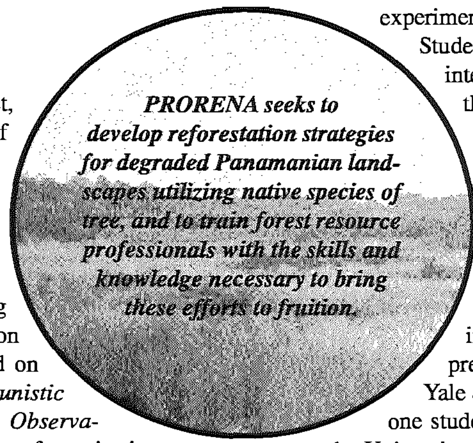
-- To develop strategies and guidelines for the restoration and reforestation of degraded areas in Panama with native species of tree within the ecological, social, and economic context of Panamanian landscapes. Such strategies and guidelines may also include the appropriate use of exotic species in restoring native forests.

-- To build upon existing knowledge to develop basic silvicultural information for Panamanian native species, facilitating their use for conservation, timber production, non-timber forest products, or other purposes.

-- To provide intensive, directed training and research opportunities for Panamanian and North American university students in the applied natural sciences.

Project Phases and Goals

PRORENA is conceived as a long-term project, able to monitor the growth and development of reforestation projects through maturity. The essential functions and structure of PRORENA will be established in two phases.



The first phase, begun at the initiation of the project, involves the collection and dissemination of existing information. During this phase of the project, staff are focusing on gathering information from the literature and on the establishment of *observational* and *opportunistic* experiments with each project collaborator. *Observational* experiments involve the establishment of monitoring plots in existing reforestation projects; although most collaborators have a strong interest in monitoring the growth, survival, and other characteristics of their plantations, few have the resources to do so. Observational studies, although not established as statistically designed experiments, can still yield useful information, especially when data for a single species are compared across several sites. *Opportunistic* experiments involve the integration of experimental designs into ongoing reforestation activities, such that small adjustments to the operational procedures utilized by a given collaborator can yield designed experimental plots. For example, a project planting a mixture of five native species on abandoned pasturelands might easily be modified to ensure that sub-parcels, each containing the same proportional mixture of the five utilized species, be established within the project area. These sub-parcels could then be monitored and the results statistically analyzed, while the project's goals of reforestation (whether for commercial, conservation, or other purposes) are still achieved.

Other activities to be accomplished in the first phase of PRORENA include a set of analyses of current and potential markets for native species timber and non-timber products, and a series of landowner surveys to identify the constituencies most interested in reforestation, their resources, interests, and needs.

The bulk of project activities are to be accomplished by students from the University of Panama, Yale, Harvard, and other Latin and North American universities completing research and directed internships with PRORENA staff. These internships are an opportunity for students to develop individual research projects within the larger framework.

The initial results of all of these activities will be presented at the first of what is hoped to be an annual Native Species Practitioners' Workshop in Panama City in August 2001. The conference will provide project collaborators and others interested in native species reforestation with an opportunity to meet, share knowledge, and learn from each other's experiences.

Future project activities will include the establishment of designed experimental plots, and the eventual publication of a *Silvics of Panamanian Trees*. Such a publication will necessarily be a preliminary contribution, but it is hoped that within five years sufficient information will have been gathered to include 100 species in a first volume.

In collaboration with Panamanian National Environmental Authority's Center for Sustainable Development, PRORENA provides students with training in field collection techniques, experimental design, analysis, and scientific writing. Students complete their own research projects or internships with the assistance of advisors from their home institutions, the PRORENA project, and the collaborators with whom they are most directly involved. In the first six months, PRORENA has hosted two students from the University of Panama completing research on nursery management and field performance of selected native species, and one student from McGill University conducting research on large landowner reforestation preferences. This summer three students from the Yale School of Forestry and Environmental studies, one student from Yale College, and one student from the University of Panama will initiate a long-term study of a native species reforestation project that is part of a larger erosion-control effort along the Panama Canal.

The integration of academics, government officials, landholders, businesspeople, and NGOs into the research and management of reforestation projects bridges gaps between theory, science, policy, and implementation. This approach is intended to expose students and faculty to real-world conditions, empower private citizens to access academic and agency resources, and inform landowners, businesspeople, government officials, and other decision-makers of the impacts and alternatives to tropical deforestation.

References

Romero M., Arturo, A. Mosquera, and D. Vargas. 1999. La industria forestal en Panamá: consideraciones para su reconversión. Informe de Consultoria. Autoridad Nacional del Ambiente (ANAM) y Organización Internacional de las Maderas Tropicales (OIMT). Proyecto: PD – 15/97 Rev. 2.

A gendered analysis of the Uttar Pradesh Rural Water Supply and Environmental Sanitation Project

Smita Malpani, MES 2001

Introduction

Uttar Pradesh (U.P.) is India's most populous state, with an estimated 150 million people. It is also one of the poorest states, with a per capita income roughly 29 percent below the national average. U.P. also lags behind the nation in other development indicators; for example, 47 percent of the population does not have access to an adequate drinking water supply and only 2.9 percent of the population has access to sanitary facilities (Iyer, 1998).

The Constitution assigns responsibility for rural water supply and sanitation to state governments, which have traditionally used a supply-driven approach to service delivery. This approach rarely takes beneficiary preferences or needs into account, nor is there cost recovery for capital investments or operation and maintenance. Because of poor construction and management, a third of the U.P. state government's water supply infrastructure is out of order at any given time (Iyer, 1998).

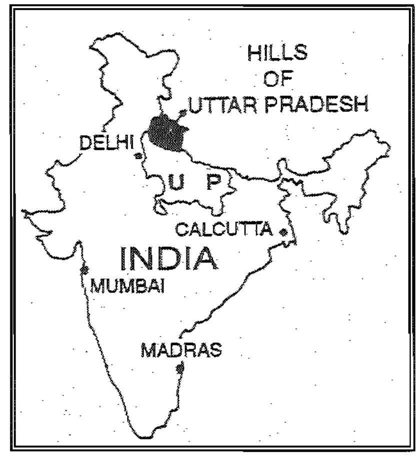
Swajal, a pilot project

To test the efficacy of an alternative demand-driven approach to water management in U.P., a pilot project was initiated in areas of the state suffering from the most drastic water scarcity. The Uttar Pradesh Rural Water Supply and Environmental Sanitation (UPRWSES) or Swajal (literally meaning "own water") Project as it is popularly referred to, is funded by a $60 million World Bank loan to the U.P. government. Implementation was initiated in 1996 and is ongoing. By the end of Phase I of Swajal, approximately 1,000 villages will have undergone the pre-planning, planning, implementation, and operation and maintenance (O&M) phases of the project (Iyer, 1996).

UPRWSES is an integrated development project with both "hardware" and "software" components. Hardware refers to those aspects of Swajal related to water supply and sanitation infrastructure such as the construction of latrines or piped water supply schemes. Upon a village's agreement to participate in Swajal, the village enters the project planning phase. During this phase, a representative Village Water and Sanitation Committee (VWSC) is formed, with a minimum one-third representation of women. Construction of infrastructure occurs during the implementation phase. The beneficiary community or household must contribute ten percent of the capital cost (one percent in cash and 9 percent with labor) of all infrastructure and 100 percent of O&M costs. A village maintenance worker responsible for overseeing day-to-day operation is hired, trained, and paid from a portion of the money regularly collected for O&M costs.

At all stages of the project, NGOs serve as support organizations and intermediaries between the village and UPRWSES' Project Management Unit. NGOs catalyze the project at every level, from technical advice to mobilization for community development, promoting the decentralized, participatory process that characterizes the Swajal Project.

The Central Himalayan Rural Action Group (CHIRAG) is one of the most active NGOs within UPRWSES, operating in 31 Swajal villages (CHIRAG, 2000). One of the strategies unique to CHIRAG is the division of labor between community workers. In some villages CHIRAG takes the money allocated for one village community worker and divides that money to pay two employees. One community worker, usually male, is primarily responsible for disseminating information and facilitating technical or "hardware" aspects of the project. Eventually, the community worker receives training to become a community technician and help engineers advise on construction of household and village-level infrastructure during the implementation phase of the project.



The other community worker, usually female, works primarily with community development initiatives which are generally focused on women. UPRWSES has significant community development and capacity-building programs that make up the "software" components of Swajal. Women are the primary focus of these activities because of their central role in family hygiene, food preparation, childcare, and the provision of water for household consumption. During the planning stage of the project, several different community development activities attempt to "enhance the role of women, who are key stakeholders" (World Bank, 1996). Software activities fall into four major categories: public participation, health education and sanitation (HESA) training, informal education, and women's development initiatives (WDI).

In Swajal project documents, women are acknowledged to be the primary beneficiaries of UPRWSES due to their traditional responsibilities for water supply and hygiene. However, it is still unclear whether and how women's lives are actually changed by Swajal after its implementation. Evaluation and critical analysis can be used as tools to provide perspective on project design and methods of implementation. NGOs, as flexible and dynamic institutions, are particularly capable of incorporating lessons learned in future operations.

Field Sites

Matela:

Located about 1 km from the nearest road and 10 km from the nearest town, Matela is comprised of 22 families of the same *jaat* (subcaste). Almost without exception, these families live below the poverty line. Approximately half of the households are clustered fairly close together (lower Matela). The remaining households are scattered farther apart at higher altitudes (upper Matela). The UPRWSES project has been the only CHIRAG intervention in Matela to date.

An overwhelming percentage of men leave Matela to search for primarily low wage work in nearby cities. Women are left to manage the household, raise children and eke out a living from family land. The women of Matela grow the food that is the primary source of sustenance for their family, gather fodder for their animals, find fuel for cooking, and collect water for the household. Typically, women of upper and lower Matela collect water from different sources.

Prior to the Swajal project, Matela suffered from acute water scarcity. In view of the pressing need to mitigate severe water shortages, project management authorities relaxed feasibility guidelines and allowed lower Matela to be slated for Swajal implementation. In addition to drastic seasonal water shortages, the village had an almost complete lack of sanitation facilities.

Women and girls are responsible for animal husbandry

Simayil

The second village selected for study, Simayil, is comprised of 98 households, and is relatively prosperous. Although not located as close to a metropolitan center as Matela, Simayil is a roadside village. Much of Simayil, like Matela, is comprised of one *jaat*. The revenue village of Simayil is composed of several hamlets, each of which actually identifies with the village to varying degrees. A revenue village is set up by the government as a unit for administration and development; it does not always correspond to residents' conceptions of their community.

CHIRAG and Simayil have had a long and successful history of working together. Prior to the advent of Swajal in this village, CHIRAG worked with residents on a number of initiatives, including increased sanitation facilities, social forestry, education and health care. Residents identify Mother Dairy, an agricultural cooperative that provides transport and a link between Simayil's farmers and urban markets, as an especially important and effective project. In contrast to Matela, the village's agriculture is no longer primarily for subsistence purposes. Villagers maintain that Mother Dairy and other CHIRAG projects have greatly increased the prosperity and quality of life in Simayil.

The water supply situation in Simayil is complex. Some residents primarily use old, unreliable government pipelines. Others use water supply infrastructure set up by Swajal. A handful of households have private connections for water in their homes. In general, seasonal water shortages in Simayil prior to Swajal were not as extreme as in Matela.

Methodology

After selecting the two villages for study, a methodology was chosen that used semi-structured interviews supplemented with observer techniques (Fontana and Frey, 1994). Interviews were primarily directed toward women; however, some women reluctant to speak to an outsider with their husbands present would let their spouse dominate the interview. In these instances, attempts were made to return to speak with women when they were more at liberty to discuss their opinions. A few questions were formulated to initiate a conversation about the Swajal project:

-- How has the Swajal project changed things?
-- Can you tell me what women's roles have been in the Swajal project?
-- What is the history of the women's self-help group?
-- What do you do with time saved from collecting water?
-- What is your opinion of the Swajal project?

Some women in Matela and Simayil not used to speaking in Hindi were more comfortable speaking in the local dialect. For this reason, field assistants accompanied me during most interviews.

Results

Planning

According to UPRWSES guidelines, women were a part of VWSCs in both Matela and Simayil. According to CHIRAG staff, women participating in the Matela VWSC were active and vocal. It is not clear how women participated in the Simayil VWSC. In general, it was very difficult to assess how mandated participation of women in village VWSCs affected the Swajal Project in the village or women's participation as a whole in the village.

Implementation

Similarly, it is unclear how effective Women's Development Initiatives (WDI) training has been in effecting its two major goals. The first of these goals is to provide skills training for women to boost income generation. This goal is based on the assumption that making the water supply closer and more reliable will save time, and that women will be able to productively use this time for income generation. The second of these goals is to catalyze the formation of small collective women's groups to increase access to credit and aid in initiation of income generation activities.

Most women agreed that it took much less time to collect water after the advent of the Swajal Project. Despite this, many returned questions about "time saved from collecting water" with blank looks. Some women in Matela contended that making water more accessible did not actually result in time saved. Proximity of water mandated increased time spent on animal husbandry, and household chores such as washing clothes or cleaning. Others acknowledged that there were significant time-savings, and responded that they spent this time on more childcare and fuelwood and fodder collection. Interestingly, neither women in Simayil nor Matela responded that they used skills gained from WDI training to generate income during the time saved from collecting water.

The WDI training programs in Matela taught sewing and improved agricultural techniques. In Simayil, they taught sewing, making preserves, and agriculture. In both Simayil and Matela, a few women responded that sewing training was useful, saying that they were able to save money because they were better able to mend their children's clothes. However, most women found they could not use these skills because training was conducted on sewing machines.

Most women do not own sewing machines, as they are only occasionally given as part of a dowry.

Women in Simayil responded that they sometimes used techniques learned from WDI training to preserve fruits or vegetables, citing these skills as more relevant than sewing training. Although the majority of women in Simayil believed that they could reproduce the preserving techniques at home, no one used this training to sell products or generate income.

WDI agriculture training proved to be fairly useful to women in Matela. Prior to the UPRWSES Project, there was a limited amount and variety of crops which families were able to grow. However, with the proximity of water and WDI training, women are now able to grow crops beyond subsistence yields as well as vegetables for sale on nearby urban markets. Four years after UPRWSES implementation, sale of crops is now the major source of income for three households.

The second goal of the women's development initiative, to catalyze formation of women's savings groups, has been very successful in Simayil. As of August 2000, the 22-member savings group had collected Rs. 15,000. The group has already made several loans to its members. Although some loans went to help women purchase vegetable seed for cash crops, others were not used for income generation. Loans were also given for wheat seed to be used for subsistence purposes and also for routine home maintenance. Perhaps the most interesting use of a loan was by a woman who borrowed money and used it to ameliorate financial hardship after her husband died. This example illustrates that women in Simayil have developed financial support structures outside the family sphere. All loan recipients agreed that the women's savings group was of tremendous help to them, whether the loan was used for income generation or not.

In contrast, the women's savings group in Matela disintegrated very quickly after implementation of the project and CHIRAG's withdrawal from the village. Many reasons were given for the group's breakup, although all respondents admitted that they had no conclusive explanation for why the group had not persisted. Some women complained that the group had been too time consuming and that their work did not allow them to attend meetings. Others observed that men were not always willing to permit their wives to participate; still others noted that they could not save Rs. 10 every month to pay dues.

O&M

Improved water supply in lower Matela resulted in more dramatic changes than occurred in Simayil, perhaps due to the severity of water scarcity in Matela. Following the installation of a tank for piped water, women cited several positive changes. First, an increased water supply made it possible for the majority of households in lower Matela to keep buffaloes which, unlike cows, require a good deal of maintenance. While cows can be set free to graze and find water, buffaloes must be fed, groomed and given water to drink. Despite their drawbacks, buffaloes are highly valued because they can produce milk in excess of household consumptive needs; this excess can be sold to nearby markets, boosting household income. In this way, the Swajal Project's goal of enhancing rural incomes has been indirectly met. In this instance, it was not through WDI or skills training, but the mere augmentation of a scarce resource that enabled this development.

Some 15-20 year old girls cited another important way the project changed their lives. Before the advent of Swajal, girls were sometimes either kept home from school or too tired to attend

Women and girls are also responsible for fodder collection

because of their responsibility to help collect water, especially during difficult dry seasons. With reduced collection time, girls in Matela reported that they have more time to focus on their schoolwork.

Although women's lives in both Matela and Simayil have improved because of Swajal, they did not report being actively involved in Swajal's management during the 20 year O&M phase of the project. The village maintenance worker, who has always been a man, collects fees for O&M expenses of the project and is responsible for its upkeep.

Discussion

Overall, the women of Simayil and Matela believed the Swajal Project greatly improved the quality of their lives and praised CHIRAG staff. Although results of this research were not able to provide conclusive answers to all questions raised, it is clear that all facets of the project were not an unqualified success. Some recommendations can therefore be made for improving operations and for elucidating future avenues of inquiry.

Planning

Although a minimum representation of women is guaranteed in VWSCs, it is possible that women who are more affluent or active are recruited to join the VWSC, while the interests of women of other classes may not be represented. Further examination of this question is necessary in villages where the class and caste system is stratified.

It may be that informal contact with CHIRAG staff is more important than mandated, formal participation in promoting women's involvement. In Matela, for example, women said that they never would have been able to speak about Swajal at village-level forums if CHIRAG staff had not encouraged them to attend and participate. Similarly, in Simayil, women said that interaction with CHIRAG staff over a twelve year span was the primary reason women were both active and articulate in Swajal and other NGO interventions. This may be an indication that merely mandating quotas is a relatively ineffective way of boosting women's participation. Their public participation is greatly increased by understanding and supportive relationships developed with NGO staff. Therefore, women's capacity to participate is best developed through long-term association that cannot be contained within a 33 month project cycle.

Implementation
WDI training in agriculture was useful to women in both Simayil and Matela; however, other skills training did not prove useful in generating income. This may be for several reasons. First, the burden of work on women may simply be too high to make income generation through sewing or preserve-making an option. During busy seasons, women already spend up to 18 hours a day engaged in labor-intensive tasks. Second, women lack access to markets where they might sell most products. Farmers in Matela and Simayil were able to simply give their crops to a middleman to sell on the market. However, market links for other products were not established. For WDI training programs to be successful, Swajal's support organizations must move beyond mere skills provision to improving women's access to markets for different products. This is an involved proposition, and may not be feasible within the short duration of the project cycle.

O&M
Women in both villages reported that, in the short time Swajal has been in the O&M phase, it has been immensely beneficial; however, they also said that they do not have a sense of ownership of the project. This may be in part because women were not as actively involved in the hardware aspects of the project as they were in the software. Completion of the implementation phase signals the end for software programs, with the exception of the women's savings group.

Since it is primarily the hardware that persists in the O&M phase, women should be encouraged to participate in technical aspects of UPRWSES, for instance by recruiting them for training as village maintenance workers. Experience with other drinking water and sanitation projects in South Asia has shown that social and cultural factors are not barriers to women's involvement in "hardware" aspects, that women are able to handle technical training as well as men, and that they are more likely to carefully maintain infrastructure since they are the primary beneficiaries (Hoque, 1995).

Conclusion

The Swajal project has made an invaluable improvement in women's lives. CHIRAG staff were successful in helping Matela and Simayil plan and implement a project which satisfies demand for more reliable water supply and increased sanitation. However, if development is to be viewed as process-oriented rather than goal driven, the Swajal project design limits the support organization's ability to realize the potential of its software aspects and its goal of enhancing women's participation in development.

First, and perhaps most importantly, increasing women's public participation and promoting income generation may not be feasible within a 33 month project cycle. The strict timeline may inherently limit the potential for capacity-building initiatives to endure. Second, women should be actively encouraged to participate in hardware aspects of UPRWSES. Without their participation in technical decision-making and activities, women cannot be said to be truly participating in Swajal and risk being marginalized. Third, all women's public participation must be encouraged. Although mandating women's representation on VWSCs is a positive step, support organizations must continue to build relationships that are the backbone of the development process. Without these personal links, women's full participation will not be realized. Long-term, genuine encouragement and support of women's capacity is a prerequisite for articulation of women's concerns and ideas. Without significant contribution from Swajal's primary beneficiaries, the project cannot be said to be truly participatory.

References

Central Himalayan Rural Action Group. 2000. 13th Annual Report.

Fontana, A. and J. Frey, Interviewing: 1994. The Art of Science. Chapter 22 in *Handbook of Qualitative Research* (N. Denezin and Y. Lincoln, eds.). Newbury Park: Sage.

Hoque, B.A. August 1995. Women's involvement in a water and sanitation project in rural Bangladesh. in *Gender, Health, and Sustainable Development: perspectives from Asia and the Caribbean* (J. Roberts, J. Kitts, and L. Arsenault, eds.). International Development Research Centre.

Iyer, P. May 1998. Uttar Pradesh State, India: The Swajal Project-Experiences with Implementing a Demand-Responsive Approach. paper presented at the Community Water Supply and Sanitation Conference, UNDP-World Bank Water and Sanitation Program.

Iyer, P. 1996. The Swajal Project: A New Approach. paper presented at the 22nd WEDC Conference.

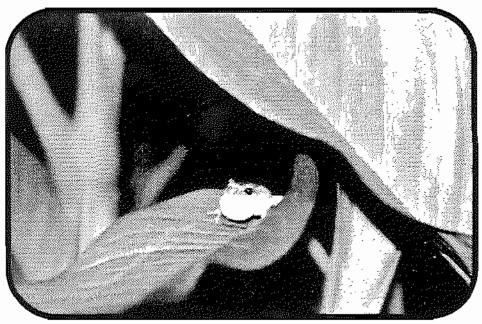
World Bank Staff Appraisal Report. 28 May 1996. India: Uttar Pradesh Rural Water Supply and Environmental Sanitation Project.

The effect of a juvenile terrestrial frog, *Eleutherodactylus coquí*, on the decomposer food web and leaf litter decomposition rate in the wet forests of Puerto Rico

Karen H. Beard, PhD 2001

Introduction

The developmental shifts that characterize an organism's life cycle are often associated with changes in resource use (Werner and Gilliam 1984). These changes are particularly striking in amphibians, since many of them have both aquatic and terrestrial life phases. However, most research on amphibians focus on only one phase of their life cycle (Kats et al. 1988, Wellborn et al. 1996), even in studies attempting to assess the role a species plays in ecosystem processes (e.g., Seale 1980). For amphibians whose ontogenetic shifts are characterized by direct development rather than the dramatic water-to-air transition that biphasic species exhibit, even less emphasis is usually placed on differentiating the roles of the different phases (except see Townsend 1985). However, even these subtler phase shifts may cause such significant alterations in resource use that the net ecosystem effects of different phases of the same species may be diametrically opposed (Polis 1984). A species must therefore be studied throughout its life cycle in order to create a complete picture of how it affects ecosystem function.



A juvenile Eluetherodactylus coqui

The most abundant nocturnal vertebrate species in the subtropical wet forests of Puerto Rico is the terrestrial frog, *Eleutherodactylus coqui*, commonly known as the coquí. While adults of this species have been found to play important roles in the community and ecosystem (Beard, 2001), differences between the juvenile and adult life phases suggest that each plays a unique role. Juveniles remain closer to the forest floor than do adults (Townsend 1985); they also have higher densities, outnumbering adults by a ratio of 5.3:1 (Stewart and Woolbright 1996). In addition, juveniles consume more and smaller prey items than adults (Townsend 1985).

Juvenile coquí densities in Puerto Rican forests approach 50,000 individuals per ha; these populations consume approximately 100,000 invertebrates per ha per night (Stewart and Woolbright 1996). However, no studies have determined whether juveniles regulate invertebrate populations. Previous studies on the role of juveniles in the leaf litter community have yielded contradictory expectations. While some studies suggest that juveniles do not consume leaf litter invertebrates (Townsend 1985) and that they avoid leaf litter due to its high predation risk, others believe that most of their prey are actually associated with the forest floor (Lavigne and Drewry 1970) and that population size is positively correlated with heavy leaf litter (Stewart and Woolbright 1996).

Juvenile coquís have the potential to affect nutrient availability in the leaf litter in two ways. First, consumption of detrital feeders can have a cascading effect on the rate of leaf litter decomposition (Wyman 1998). Second, nitrogenous waste deposition may affect decomposition rate (e.g., Kitchell et al. 1979, Ruess and McNaughton 1987, Lovett and Ruesink 1995); this is particularly likely considering the high densities of juvenile coquís and their proximity to the forest floor. Thus far, no studies have been conducted to determine this species' role in ecosystem processes such as nutrient availability.

The objectives of this study were to determine the effects of juvenile coquís on (1) the leaf litter invertebrate community, (2) leaf litter decomposition rate, and (3) leaf litter chemical composition. Predation on detrital-feeding invertebrates and excrement deposition were expected to be the main causal factors of any changes in these parameters. Results were compared to similar experiments conducted using adult coquís (Beard 2001) to determine whether the two life-history phases play different roles.

Study Site

The study site was located in the Bisley Watersheds, Luquillo Experimental Forest (LEF), Puerto Rico (18°18'N, 65°50'W; 28ha), a subtropical wet forest (Holdridge 1970) with a weakly seasonal climate (Briscoe 1966). Experiments were conducted in the secondary Tabonuco (*Dacryodes excelsa*) forest zone, uphill from Bisley Stream #1 and downhill from the main road at 250 m elevation. The 5 m x 10 m area used was chosen so that it was located at least 15 m from the main road and any other research areas.

Methods

Sixteen pyramid-shaped enclosures were constructed using 0.25 m^2 of 3 mm wire mesh as the base of each enclosure and 2 mm plastic mesh screening for the sides. A 0.40 m length and 0.02 m diameter PVC pipe was placed in the center of each cage for support (volume of each enclosure=0.10 m^3).

In order to create natural substrate and introduce invertebrates, 200 g of wet leaf litter were added to the bottom of each enclosure. Two leaf litterbags containing 5 g each of air-dried mixed litter collected near the study site (Swift et al. 1979, Anderson and Swift 1983) were placed underneath each cage. Subsamples of air-dried leaves were separately processed after every fifth litterbag was constructed in order to convert air-dried to oven-dried weights.

Paired control and experimental enclosures were placed in the field. Enclosures were left unsealed for one week to allow additional invertebrates to colonize the enclosures. 45 juvenile coquís ranging in size from 10-20 mm snout-vent length (SVL), were caught in the Bisley Watersheds; frogs are considered pre-adult when SVL is less than 24 mm (Woolbright 1985). To simulate high natural densities, three juveniles were placed in each of 8 enclosures. The other 8 were controls and contained no frogs. All enclosures were sealed using fishing line. The 16 enclosures remained in the field for 3 months, from July through September 1999.

Given that juvenile coquís have an 81% chance of mortality within their first year of life (Stewart and Woolbright 1996), loss of juveniles due to predation was expected during the experiment.

To control for this, frogs were counted and replaced with similar-sized frogs biweekly. Four frogs were removed from enclosures at the termination of the experiment and analyzed for stomach content. Prey items from the stomach content were identified to scientific order whenever possible.

Leaf litterbags were retrieved when the enclosures were removed from the field. Following removal of adhering living plant parts and soil, the contents of each litterbag were oven dried at 70° C until constant weight was achieved. Samples were then ground and a subsample from each tissue was ashed overnight at 500° C for conversion to ash-free weight. Leaf litter dry weights were measured at the initiation and termination of the experiment and compared to determine biomass loss. Leaf litter samples were then analyzed for total carbon (C) and nitrogen (N) using a LECO CNH-600 Elemental Analyzer (Bremner 1996) and results corrected for mineral contamination (Bloomfield et al. 1993, Palmiotto 1998).

Leaf litter remaining on the bottom of each cage was carefully collected when the cages were removed from the field. Leaf litter invertebrates were extracted from the material using Tullgren funnels and identified to scientific order. The invertebrates were categorized according to feeding guild: detrital feeders (Acarina, Coleoptera, Collembola, Dermaptera, Diplopda, Isopoda, Isoptera), plant feeders (Gastropoda, Hemiptera, Homoptera, Larvae), and predators (Araneae, Chilopoda, Diptera, Hymenoptera, Pseucoscorpionida), as determined from the literature (Dial 1992, Goldwasser and Roughgardner 1993, Garrison and Willig 1996, Pfeiffer 1996a, Pfeiffer 1996b).

Statistical analyses were conducted using SAS for Windows 6.12 (SAS 1990). The variables analyzed were number of individual invertebrates in leaf litter, leaf litter decomposition rate, and leaf litter chemical change. For each variable, t-tests for paired means were used to compare the eight enclosures containing coquís to the eight control cages. Assumptions of normality were met when necessary with log transformations. Results are reported with non-transformed values. A pre-specified level of significance was set at 0.10; actual p-values are given below.

Figure 1: Mean invertebrate abundance (+SE) in total and per feeding guild, in enclosures with and without juvenile coquis

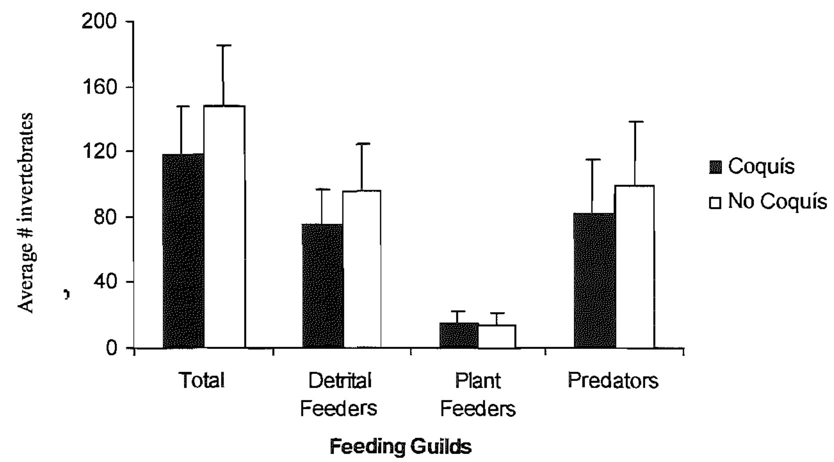
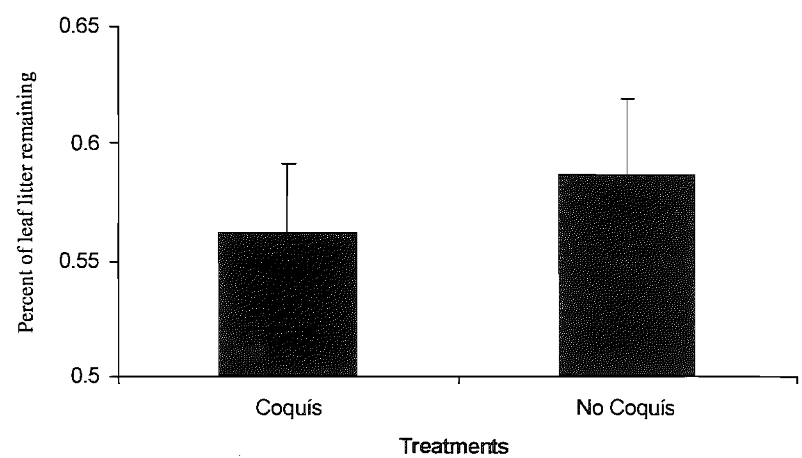


Figure 2: Percent biomass remaining (+SE) in leaf litter decomposition bags in enclosures with and without juvenile coquis



Results

Juvenile coquís in the enclosures had a 92% survival rate during the three month experiment. Stomach analyses of four individuals indicated that the average coquí consumed 6.5 invertebrates per night. The invertebrates found in the stomachs belonged to the orders Hymenoptera (wasps and ants) (38.4%), Araneae (19.2%), Coleoptera (15.4%), Diptera (7.7%), Acarina (3.8%), Isopoda (3.8%) and Coleoptera larvae (3.8%).

The majority of invertebrates in the enclosures fell into the orders Acarina (19.97%), Araneae (18.09%), Isopoda (16.04%), Hymenoptera (11.94%), Collembola (11.74%), Diptera (6.56%), Diplopoda (5.11%), Hemiptera (3.06%), Homoptera (2.45%), Larvae (2.29%), and Coleoptera (2.08%). Other orders present in lower percentages (<1%) included: Chilopoda, Dermaptera, Gastropoda, Isoptera, Lepidoptera, Pscocptera, and Pseudoscorpionida.

The number of detrital feeders extracted from the litterbags was negatively affected by the presence of coquís (P=0.06; Fig. 1). However, the numbers of phytophagous and predatory invertebrates were not affected (P=0.90, 0.18, respectively), nor was the total number of invertebrates (P=0.14).

Enclosures which contained juvenile coquís had significantly faster leaf litter decomposition rates than did enclosures in which they were excluded (P=0.02; Fig. 2). The chemistry of decomposing leaf litter, including total C (P=0.70), total N (P=0.97), and C:N ratio (P=0.86), was not significantly altered by the presence of coquís.

Discussion

Over the course of 3 months during which high densities of juvenile coquís were held in enclosures with their prey, the number of invertebrates in the enclosures did not significantly decline. In addition, the average number of invertebrates found in stomachs after 3 months in the enclosures was similar to the average number reported in juvenile stomachs in the field (Stewart and Woolbright 1996), suggesting that juvenile coquís had sufficient food resources during the experiment. These results suggest that leaf litter invertebrates do not limit juvenile coquí populations.

Juveniles appeared to be consume prey selectively, favoring detrital feeders over phytophagous or predaceous invertebrates as evidenced by the presence of detrital feeders in the stomach analysis that were not well represented in the enclosures. Surprisingly, predaceous invertebrates were not positively affected by the presence of coquís, even though some of them prey on the juvenile frogs. One potential explanation is that coquís are effective at hiding from predators (Huffaker 1958). An alternative hypothesis is that juvenile coquís are not only prey but also effective competitors and/or predators of these invertebrates. Phytophagous invertebrates were present in the enclosures, albeit in low densities as was to be expected considering the absence of plants. These invertebrates, particularly Hemiptera and Homoptera, were notably absent from the stomach content analysis however, suggesting the possibility that litter invertebrates are more important in juvenile coquí diets than herbivorous invertebrates.

Karen collecting leaf litter

The decrease in detrital feeder populations associated with the presence of juvenile coquís suggested that the latter may exert top-down control on the detrital food web and indirectly reduce litter decomposition rates (Hanlon and Anderson 1979, Ineson et al. 1982). However, the positive association between coquís and decomposition rate suggests that juveniles increase the availability of limiting nutrients to microbes through excrement deposition (Hanlon and Anderson 1979, Hanlon 1980). Further studies should be conducted to separate these two effects. Leaf litter decomposition as represented by decreased C, increased N, and decreased C:N ratios (Berg and Staaf 1981, Melillo et al. 1982) was not associated with the presence of juveniles, although the use of mixed litter may have increased variation in C:N ratios, masking the effect of the coquís. Further studies should be conducted to determine if the quantities of other nutrients in the decomposed litter, such as those frequently found in coquí excrement, are affected by their presence.

Adult and juvenile coquís are known to have different feeding preferences based on the size of the prey they are able to consume (Townsend 1985), but the effect of prey feeding guild on preference has not been determined. This study suggests that juveniles have different feeding guild preferences from those demonstrated by adult coquís. Adults and juveniles in combination were positively associated with detrital feeders during a six month experiment (Beard 2001) while this study shows a negative association with juveniles alone, suggesting that time scale is a relevant factor not only in the quantitative but also in the species' qualitative impact on invertebrate prey populations. In addition, adult coquís limit herbivorous invertebrate populations (Beard 2001) whereas juveniles do not. While the net effects of juveniles and adults on leaf litter decomposition are similar, their effects on the leaf litter invertebrate community differ (Beard 2001), demonstrating that different life-history stages of amphibian species, even those experiencing direct development, should be considered when assessing their roles in the ecosystem.

This research is one of the few documented cases in which a non-decomposer organism directly regulates the rate at which leaf litter decomposes and therefore nutrients are mineralized in the system. Most studies have concentrated on the regulation of decomposer organisms by the chemistry of detrital tissues and abiotic variables (Swift et al. 1979, Melillo et al. 1982, Bloomfield et al. 1993, Scheu and Schaefer 1998). In this study, an amphibian strongly influences the rate at which decomposers function. Whether this species represents an unusual case or whether the interactions discussed here have wider relevance for other ecosystems should be the subject of further research.

Acknowledgements

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References

Anderson, J. M., and M. J. Swift. 1983. Decomposition in Tropical Forests. Pages 287-309 *in* S. L. Sutton, T. C. Whitmore, and A. C. Chadwick, editors. Tropical Rain Forest: Ecology and Management. Blackwell Scientific Publications, Oxford.

Beard, K. H. 2001. The Ecological Roles of a Terrestrial Frog, *Eleutherodactylus coquí*, in the Nutrient Cycles of a Subtropical Wet Forest in Puerto Rico. Ph.D. Dissertation. School of Forestry & Environmental Studies. pp. 187.

Berg, B., and H. Staaf. 1981. Leaching, accumulation, and release of nitrogen in decomposing leaf litter. Ecol. Bull. 33:163-178.

Bloomfield, J., K. A. Vogt, and D. J. Vogt. 1993. Decay rate and substrate quality of fine roots and foliage of two tropical tree species in the Luquillo Experimental Forest, Puerto Rico. Plant and Soil 150:233-245.

Bremner, J. M. 1996. Nitrogen-Total. Pages 1085-1122 *in* J. M. Bigham, editor. Methods of Soil Analysis Part 3: Chemical Methods. Soil Science Society of America, Madison, Wisconsin.

Briscoe, C. B. 1966. Weather in the Luquillo Mountains of Puerto Rico. Research Paper No. 3 U.S. Institute of Tropical Forestry, Rio Piedras, Puerto Rico.

Dial, R. 1992. A Food Web for a Tropical Rain Forest: The Canopy View from *Anolis*. Ph.D. Dissertation. Stanford University, Palo Alto, California.

Garrison, R. W., and M. R. Willig. 1996. Arboreal Invertebrates. Pages 183-246 *in* D. P. Reagan and R. B. Waide, editors. The Food Web of a Tropical Rain Forest. University of Chicago Press, Chicago.

Goldwasser, L., and J. Roughgardner. 1993. Construction and analysis of a large Caribbean food web. Ecology 74:1216-1233.

Hanlon, R. D. G. 1980. Influence of macroarthropod feeding activities on microflora in decomposing oak leaves. Soil Biol. Biochem. 12:255-261.

Hanlon, R. D. G., and J. M. Anderson. 1979. The effects of Collembola grazing on microbial activity in decomposing leaf litter. Oecologia 38:93-99.

Holdridge, L. R. 1970. A System for Representing Structure in Tropical Forest Associations. Pages 147-150 *in* H. T. Odum and R. F. Pigeon, editors. A Tropical Rain Forest: A Study of Irradiation and Ecology at El Verde, Puerto Rico. Division of Technical Information, U.S. Atomic Energy Commission.

Huffaker, C. B. 1958. Experimental studies on predation: dispersion factors and predator-prey oscillations. Hilgardia 27:343-383.

Ineson, P., M. A. Leonard, and J. M. Anderson. 1982. Effect of collembolan grazing upon nitrogen and cation leaching from decomposing leaf litter. Soil Biol. Biochem. 14:601-605.

Kats, K. B., J. W. Petranka, and A. Sih. 1988. Antipredator defenses and the persistence of amphibian larvae with fishes. Ecology 69:1865-1870.

Kitchell, J. F., R. V. O'Neill, D. Webb, G. A. Galepp, S. M. Bartell, J. F. Koonce, and B. S. Ausmus. 1979. Consumer regulation of nutrient cycling. BioScience 29:28-34.

Lavigne, R. J., and G. E. Drewry, editors. 1970. Feeding Behavior of the Frogs and Lizards in the Tropical Wet Forest: Preliminary Report. Puerto Rico Nuclear Center, Rio Piedras, Puerto Rico.

Lovett, G. M., and A. E. Ruesink. 1995. Carbon and nitrogen mineralization from decomposing gypsy moth frass. Oecologia 104:133-138.

Melillo, J. M., J. D. Aber, and J. F. Muratore. 1982. Nitrogen and lignin control of hardwood leaf litter decomposition. Ecology 63:621-626.

Palmiotto, P. 1998. The Role of Specialization in Nutrient-Use Efficiency as a Mechanism Driving Species Diversity in a Tropical Rain Forest. Ph.D. Dissertation. Yale University, New Haven.

Pfeiffer, W. J. 1996a. Arboreal Arachnids. Pages 247-272 *in* D. P. Reagan and R. B. Waide, editors. The Food Web of a Tropical Rain Forest. University of Chicago Press, Chicago.

Pfeiffer, W. J. 1996b. Litter Invertebrates. Pages 137-182 *in* D. P. Reagan and R. B. Waide, editors. The Food Web of a Tropical Rain Forest. University of Chicago Press, Chicago.

Polis, G. A. 1984. Age structure component of niche width and intraspecific resource partitioning: can age groups function as ecological species? American Naturalist 123:541-564.

Ruess, R. W., and S. J. McNaughton. 1987. Grazing and the dynamics of nutrient and energy regulated microbial processes in the Serengeti grasslands. Oikos 49:101-110.

SAS. 1990. SAS/STAT User's Guide. SAS Institute, Cary, NY.

Scheu, S., and M. Schaefer. 1998. Bottom-up control of the soil macrofauna community in a beechwood on limestone: Manipulation of food resources. Ecology 79:1573-1585.

Seale, D. B. 1980. Influence of amphibian larvae on primary productivity, nutrient flux, and competition in a pond ecosystem. Ecology 61:1531-1551.

Stewart, M. M., and L. L. Woolbright. 1996. Amphibians. Pages 363-398 *in* D. P. Reagan and R. B. Waide, editors. The Food Web of a Tropical Rain Forest. University of Chicago Press, Chicago, Illinois, USA; London, England, UK.

Swift, M. J., I. N. Healy, and J. M. Anderson. 1979. Decomposition in Terrestrial Ecosystems. Studies in Ecology. University California Press, Berkeley.

Townsend, D. S., M. M. Stewart, F. H. Pough, and P. F. Brussard. 1981. Internal fertilization of an oviparous frog. Science 212:469-471.

Townsend, K. V. 1985. Ontogenetic Shift in Habitat Use by *Eleutherodactylus coqui*. Master's Thesis. State University of New York, Albany.

Wellborn, G. A., D. K. Skelly, and E. E. Werner. 1996. Mechanisms creating community structure across a freshwater habitat gradient. Annu. Rev. Ecol. Syst. 27:337-363.

Werner, E. E., and J. F. Gilliam. 1984. The ontogenetic niche and species interactions in size-structured populations. Ann. Rev. Ecol. Syst. 15:393-425.

Woolbright, L. L. 1985. Sexual Dimorphism in Body Size of the Subtropical Frog, *Eleutherodactylus coqui*. Ph.D. Dissertation. State University of New York, Albany.

Interview with Herb Bormann

Douglas Morton, MEM 2002

Recently, the staff of TRI News had the chance to discuss the fall course on tropical forest ecosystems (FES 574), the current status of tropical ecosystem studies, and the lifestyle of busy retirement with Herb Bormann, co-founder of the Hubbard Brook Ecosystem Study and Professor Emeritus at the Yale School of Forestry and Environmental Studies.

How did you get involved with teaching FES 574, The Ecology of Tropical Forest Ecosystems, with your former students, Dan Nepstad and Chuck Peters?

H.B. I have kept in close touch with both Dan and Chuck since they finished their work at Yale, and I thought the course sounded like a great idea when they approached me about it. I protested at first—but eventually realized that I might be able to offer comments that would place class discussion in the bigger picture. I personally enjoyed the students' comments, and thought that the class was a great success.

When did you start advising doctoral students whose projects were in the tropics?

H.B. One of the very first students I had at Yale was a fellow named Paul Harcombe, who now teaches at Rice University. His study focused on successional dynamics after forest cutting in Costa Rica. At that time, most research in the tropics was purely observational, but Paul's work was experimental, and quite a good study. I also taught a course in tropical ecosystems, focused on Puerto Rico. Every year, I would take my field trip down there. We looked at ecosystem ecology, but we also dealt with social ecology, economics, race relations, you name it!

What are the most applicable lessons from Hubbard Brook for work in the tropics?

H.B. Perhaps the most important thing is to apply ecosystem thinking to tropical problems. In the tropics, is it really a question of species loss? Or, is it the impingement of whatever you are doing on the function of ecosystem processes in ways that are really negative to the long-term function of those systems?

I think that's the most important thing that comes out of Hubbard Brook, that you really have to think that way. I personally think that the understanding the functioning of systems that supply our environment with clean air and clean water are more important questions than those at the species level.

On that note, I just read a fantastic book, *Rare Earth*, written by a geologist and a paleontologist. Their thesis is that unicellular life is probably pretty common in the universe, but that more advanced, multi-cellular life, like we see in our geologic record, is quite rare—possibly even unique. You realize, looking at the Earth in the context of geologic time and universal scale, that we are working with such a small sliver of the total picture. Humans are a geologic force, but, I must say, after reading that book, you realize just how small a force we are!

Based on insights from Hubbard Brook, we developed an understanding of ecosystem function. Recently, the conservation community have reverted back to reverence for the awesome biodiversity of life on the planet, and forgotten the lessons of ecosystem ecology. How do we get an ecosystem function perspective back without having to resort to "ecosystem services" as a marketing tool?

H.B. To get away from the services concept, one has to develop a certain humility and respect for what has come before, and what is going on at this very instant. What is so damning about the services idea is that instead of us being armed with respect and care, we are armed with a bottom line figure. I just don't like that. Although, you have to realize that we are a force, and we like to live a good life. In the process of rearranging the Earth in our favor, we have had many successes. However, it is one of the most difficult things to have a philosophy of moderation. We are lured into lifestyles that have very strong implications for the environment.

You seem to have your foot in many doors these days—what kinds of things are you working on right now?

H.B. Well, I'm writing this wonderful mystery novel with my wife called *Watershed Down*. What the book has done is to allow me to express opinions that I think are somewhat thoughtful. It's been a wonderful way to put things on paper that I think, for the most part, are reasonable criticisms of what's going on. And, that's been very nice.

I have had so much reward, working in this field. I love nature. It just fills me with delight. To be able to do this in a professional way, finding out little secrets, is just so great.

What do you think are some of the most important research questions to ask about the tropics today?

H.B. I suppose one very broad question is what kind of a mix do you need between nature and human controlled environments to support human populations into the future?

Does tropical work necessitate a more applied approach than temperate work?

H.B. The amount of effort that has gone into understanding the biology and natural history of tropical regions is miniscule when compared with the efforts in temperate regions. Temperate regions have been studied and documented, in large part, by universities and governments for a long time. Biologically speaking, tropical regions are much, much richer than temperate zones. In terms of research, I wonder, do we really have to relive the history of the temperate zone—starting out with taxonomy, and building on that base? Is there a way to short-cut that? I think our approach in the tropics has to be different. In some ways, as both Dan and Chuck emphasized in the fall class, you can look at ecosystem properties, like the amount of chlorophyll per hectare, forgetting about the species, and start to model the system that way. I think that might be a more profitable way to go.

Also, I am working with Gordon Whitney and several others to try to write a book about pin cherry in the northern forests. We're trying to use the species as a vehicle to explore how an ecosystem has a series of internal controls that come into place after a disturbance that act to return biotic control. We have loads of data on this, and I hope we can make a book out of it, but it's very hard—we're all busy. I have another paper that I've been working on for ten years—I have nine versions of it. It's on the "global environmental deficit." Although I gave up on it a few years ago, it seems to be pertinent, given the current administration. I also am trying to keep in shape by playing squash. I took up squash again and I'm amazed . . .at least I can keep Gabe Benoit busy on the court!

I'm worried about starting my garden up in New Hampshire—I just talked with Gene Likens this morning, and he said they still have three feet of snow up there.

Thank you.

H.B. Thank you too, this was fun.

Important allometric characteristics of native pioneer species for potential use in forest restoration in Sri Lanka

Uromi Manage Goodale, MFS 2001

Introduction

A recurring theme throughout the world is the degradation of forest regions -- from clearing, cultivation and subsequent abandonment -- leading to desertification and savannization. In Sri Lanka, high population densities and a scarcity of land have led to the destruction of much of the wet-zone forests. Only 9% of the lowland wet zone was estimated to be forested in 1985 (Sri Bharathie, 1985) and the national deforestation rate of 3.5% is the third highest in the Asia-Pacific Region (Cohen et al., 1995). Degraded lands in the lowland wet zone, often successionally arrested as fernlands, are prevented from regenerating naturally due to (1) site conditions no longer conducive to seedling establishment (e.g. soil nutrient depletion, fire, light obstruction); and/or (2) lack of a seed source in sufficient proximity for seed rain to reach the site. These abandoned and successionally arrested areas are candidates for reforestation.

Pioneer tree species play an important role in forest regeneration following disturbance, and may be similarly useful in restoring degraded land. Pioneer trees are defined by their requirement for light availability at the seed and seedling stages (Swaine and Whitmore, 1988). Most pioneer species have high growth rates, early reproduction, short life span, small seeds, seeds capable of dormancy, sparse branching, large leaves, and wide ecological ranges (Budowski, 1965; Swaine and Whitmore, 1978; Bazzaz, 1991). These life traits and physiological characteristics make pioneer species better competitors than late-successional species for use as initial vegetation in a degraded site (Bazzaz, 1991). Yet, despite their potential importance, the use of native pioneer species for restoration has not been studied previously in Sri Lanka.

A better understanding of the ecological variation between pioneer species is crucial if they are to be used effectively in restoration. Baker (1998) has shown that considerable variation in allometry and growth rates exists between two species of pioneers, *Schumacheria castaneifolia* Vahl and *Macaranga peltata* (Roxb.) Muell, both native to Sri Lanka. In my study, I examined the allometry of these two species and two other native pioneers; *Dillenia triquetra* (Rottb.) Gilg and *Wendlandia bicuspidata* Wight & Arn. I investigated both interspecific and intraspecific variation in growth as well as biotic and abiotic factors that could potentially cause such variation.

Specifically, I measured the allometric relationships of the four pioneer species, their surrounding competition, and gap condition. My hypothesis was that resource allocation would change with varying competition and such an effect would be visible in crown, branch, and stem growth. This paper focuses on the allometric relationship between the average crown diameter and diameter of the bole at breast height, 1.4 m above ground (dbh), for all four species using statistical regression to obtain estimates of average crown diameter for a given dbh. Information gathered in this study will be used to plan the arrangement and spacing of single and mixed species plantings of pioneer trees, and thus to begin the necessary process of restoration in the wet-zone of Sri Lanka.

Study Site and Species

This study was conducted in the secondary forests in the Sinharaja World Heritage Site (6° 21" N, 80°21" E) in the southwest wet lowland zone of Sri Lanka. Approximately 110,000 ha, the Sinharaja World Heritage site is the largest of the few remaining tracts of tropical rainforest in Sri Lanka. A survey of the reserve in 1983 using aerial photographs showed that close to 24% of the reserve was secondary or degraded forest (Banyard and Fernando, 1988). The vegetation is broadly classified as aseasonal, evergreen, dipterocarp-forest that extends over the perhumid region in south and Southeast Asia. The forest is characterized as a *Mesua-Shorea* community, an upland forest type that broadly circles the southwest foothills of Sri Lanka (De Rosayro, 1954; Gunatilleke and Gunatilleke, 1981).

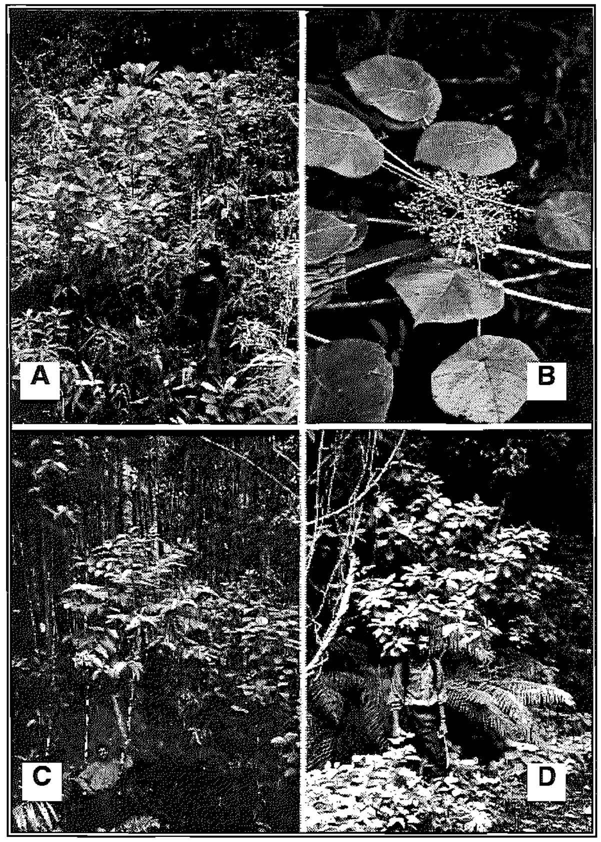


Figure 1: (A) *Dillenia triquetra* (Rottb) Gilg tree, (B)*Macaranga peltata (*Roxb.) Muell branch with fruits, (C) *Schumcheria castaneifolia* Vahl tree, (D) *Wendlandia bicuspidata* Wight & Arn.

The Sinharaja field station receives an average annual rainfall of 3900 mm, falling primarily during the southwest (April-July) and northeast (October-January) monsoons. Mean annual temperature fluctuates between 25 and 27 °C. The topography of Sinharaja consists of a series of parallel ridges and valleys that lie along an east-west axis. The sites selected were close to the Sinharaja field station at 580 m elevation. These sites were selectively logged in 1977-78. The sites on the border of the reserve adjoining Pitikele village had been periodically cleared and burned.

Four species, *Macaranga peltata* (Roxb.) Muell (Euphorbiaceae), *Dillenia triquetra* (Rottb.) Gilg (Dilleniaceae), *Schumacheria castaneifolia* Vahl (Dilleniaceae), and *Wendlandia bicuspidata* Wight & Arn (Rubiaceae) were studied in this investigation

(Figure 1). The common names of the species are Kanda, Diya para, Kekiri wara, and Wana idala respectively. These four species are commonly found in abandoned sites of shifting cultivation, skid trails, and selectively logged forests (De Zoysa et al., 1989; 1991). Taxonomic descriptions are available in the Revised Handbook to the Flora of Ceylon (Dassanayake and Clayton, 1996; 1997; 1998) and in a Field Guide to the Common Trees and Shrubs of Sri Lanka (Ashton et al., 1997).

Methods

During June-August 2000, I sampled five canopy disturbance conditions: (1) old logging landings, often close to main access roads, that remain substantially open today (three 60 m X 60 m plots), (2) main access roads for logging operations (four 30 m X 200 m transects), (3) skid trails (two 15 m X 200 m transects), (4) tree fall gaps (five 20 m X 20 m plots), and (5) recently cleared and burned forest (one 200 m X 200 m plot). All trees of the four species of height greater than 2 m encountered in gaps were marked and measured.

A total of 785 trees were measured for allometric characteristics. For each pioneer tree, diameter at breast height (dbh) was measured according to Dallmeier (1992). Crown radius (the horizontal distance from the furthest leaf to the stem) was measured from a randomly chosen point beneath the tree towards a randomly chosen direction (R_1) and then subsequently at approximately 90° (R_2), 180° (R_3), and 270° (R_4) from the original direction. This sampling strategy was based on the methods of Gregoire and Valentine (1995). The average crown diameter (ACD) was calculated as the arithmetic mean of R_1, R_2, R_3, and R_4, multiplied by two.

Total tree height and the height to the base of the live crown were measured to the nearest 0.01 m up to a height of 2.5 m, and to the nearest 0.1 m there onwards. For each tree, the degree of crown illumination was described on a scale of 1-5 according to Clark and Clark (1992).

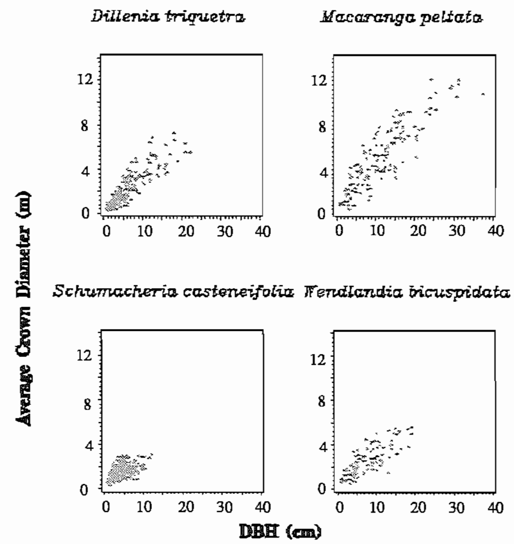
There is some disagreement as to the appropriate estimation methods for allometric relationships (Seim and Sæther, 1983; Ricker, 1984; Thomas, 1996). The average crown diameter and dbh relationship of the four species was obtained through simple linear regression models using the standard linear regression procedure of Statistical Analysis System (SAS®) (Ray, 1982; Freund and Littell, 2000). Outliers were identified from the residual plots against dbh and the studentized residual values. Out of the 785 trees sampled, 11 were identified to be outliers due to measurement errors and removed from the analysis (*Dillenia* 5 individuals, *Macaranga* 6 individuals).

The equations were evaluated in terms of measures of fit and prediction ability (Neter et.al., 1996). The correlation test of normality was used (Neter et al., 1996) to test for the normal distribution of error terms. The studentized residuals were observed using normal probability plots of the residuals to detect departure from normality. The observations of studentized residual and expected crown diameter plots, as well as the test of first and second moment specification were used to detect non-constancy of error variance (White, 1980). Pairwise comparisons were made between species for the slope parameter estimate using studentized t-test (Sokal and Rohlf, 1995). Corrections for multiple comparisons were made by the Bonferroni method (Kuehl, 2000).

Results

Average crown diameter was well correlated with dbh in *Dillenia* (r^2 = 0.82), and *Macaranga* (r^2 = 0.76). In *Wendlandia*, average crown diameter and dbh were moderately correlated (r^2 = 0.67), while in *Schumacheria*, the two variables were poorly correlated (r^2 = 0.26) (Figure 2, Table 1). T-tests for between species comparisons of the slope for the regression lines were highly significant (p<0.0001) for all pairwise comparisons.

Figure 2. Scatter plots of average crown diameter and dbh for the four pioneer species



The plots of studentized residuals of *Dillenia* clearly indicated non-constant error variance. The first and second moment specification test (α = 0.05, df = 2) confirmed non-constant error variance (heteroscedasticity) for three species and the fourth, *Macaranga*, borders significance (Table 2). The observation of the normal probability plots indicating symmetrical distribution of nearly linear error terms suggested agreement with normality for all four species. *Schumacheria* failed the correlation test of normality (α = 0.05, df = 100) (Table 2).

Using the resultant regression equations, average crown diameter both at 5 cm and 10 cm dbh was calculated, as *Schumacheria* does not usually reach 10 cm dbh (Table 3). Of the 245 *Schumacheria* trees sampled, only six exceeded 10 cm dbh; however the 10 cm calculations enabled comparison between *Schumacheria* and other species. The average crown diameter predictions were done with 90% confidence intervals as well as 90% prediction intervals that were calculated using consistent covariance estimates (Neter et al., 1996). Table four summarizes the average number of trees that need to be planted per hectare to obtain crown closure at 5 cm and 10 cm dbh assuming trees are planted at a square spacing.

Discussion

The four species of native pioneer trees investigated in this study are suitable for planting on degraded sites for reforestation and restoration. In general, the life histories of pioneer species allow very fast growth and crown expansion, changing the microclimate beneath the crown to a more moist and stable temperature environment suitable for the growth of shade tolerant seedlings and saplings (Vázquez-Yanes, 1980; Gómez-Pompa and Vázquez-Yanes, 1981; Brown and Lugo, 1990; Davies, 1996). If planted in mixture, the species-specific crown growth and leaf dynamics of these four species would produce a mosaic of light conditions under the canopy. Site observations of the four species investigated in this study showed differences in

Table 1. Regression results from analysis of average crown diameter (ACD)* and dbh** by species. Species codes are DIL = *Dillenia triquetra*, MAC = *Macaranga peltata*, SCH = *Schumacheria castaneifolia*, and WEN = *Wendlandia bicuspidata*.

Species	Number of trees	Estimated Regression Function	Coefficient of determination (r^2)	Residual mean square error	F***
DIL	263	$ACD = 0.27 + 0.29^a$ dbh	0.822	0.60381	1207.42
MAC	149	$ACD = 1.28 + 0.34^b$ dbh	0.765	1.34998	478.18
SCH	245	$ACD = 0.98 + 0.14^c$ dbh	0.258	0.52784	84.49
WEN	107	$ACD = 0.79 + 0.24^d$ dbh	0.667	0.76003	210.11

a,b,c,d Regression coefficients for slope with the same super scripted letters are not significantly different ($p<0.05$) from each other.

* ACD = Average crown diameter, in meters.

** dbh = diameter at 1.3 m above ground, in cm.

*** All F values in this table are statistically significant at 0.0001 level.

Table 2. Results from the first and second moment specification test (Spec) and correlation test of normality for the linear relationship between average crown diameter and dbh

Species	SpecChi-square value	Correlation test of normality critical value
Dillenia triquetra	45.25	0.9879
Macaranga peltata	5.65	0.9969
Schumacheria castaneifolia	9.01	0.9864
Wendlandia bicuspidata	18.51	0.9943

Table 3. 90% confidence intervals (CI) and 90% prediction intervals (PI) for the estimated average crown diameter (m) at 5 cm and 10 cm dbh

Species	90% CI at 5 cm dbh	90% CI at 10 cm dbh	90% PI at 5 cm dbh	90% PI at 10 cm dbh
Dillenia triquetra	1.73 ± 0.06	3.20 ± 0.13	1.73 ± 1.22	3.20 ± 1.33
Macaranga peltata	3.02 ± 0.99	4.70 ± 0.98	3.02 ± 2.66	4.70 ± 2.66
Schumacheria castaneifolia	1.65 ± 0.06	2.33 ± 0.13	1.65 ± 1.13	2.33 ± 1.24
Wendlandia bicuspidata	1.98 ± 0.11	3.16 ± 0.15	1.97 ± 1.52	3.16 ± 1.54

Table 4. Average number of trees per ha that needs to be planted for crown closure at 5 cm and 10 cm dbh

Species	Number of trees at 5 cm dbh	Number of trees at 10 cm dbh
Dillenia triquetra	3340	970
Macaranga peltata	1090	450
Schumacheria castaneifolia	3670	1840
Wendlandia bicuspidata	2550	1000

their site specificity. For example, *Dillenia* was commonly found in moist site conditions. In contrast, *Wendlandia* was usually found in large gaps, often growing on eroded banks; in the Pitikelle sites, I noticed it had the ability to survive periodic anthropogenic fires (Figure 3). These differences among the pioneer species give the re-forester a tool-kit for ecological restoration.

The species also differ in their allometric characteristics. The crown-dbh allometric relationship for *Macaranga* had the highest slope (Table 1), indicating that *Macaranga* is able to put more resources than the other species into crown growth rather than stem growth in order to capture and dominate the growing space. In contrast, *Wendlandia* and *Dillenia* have lower slopes indicating slower crown diameter growth. *Wendlandia* has an irregular shaped crown and a stem that leans its crown toward available light; thus the species may be better able to utilize partially shady conditions, and continue to grow even when considerably overtopped. *Schumacheria* has the lowest slope; a unit increase in dbh corresponds with a lower increase in average crown diameter. I observed that *Schumacheria* was able to maintain diverse levels of crown height (total height minus height to base of live crown) in full sun, partially shady conditions, and under full shade of other trees. This means that *Schumacheria* is able to increase crown height, at a given dbh and crown diameter, when more sunlight is available. Baker (1998) showed that *Schumacheria* had poor correlation between stem growth and crown dimensions and height. This is expected due to its fast height growth and early onset of reproductive maturity. On the whole, if the growth rates of these species are roughly comparable, then the allometric relationships suggest that *Macaranga* is the fastest to expand lateral crown growth, and *Schumacheria* the slowest; experience of villagers and forest department staff with tree growth rates supports this conclusion.

Among the four species *Schumacheria* had the lowest value for the coefficient of determination (0.26) for the regression equation; log-log transformation did not improve this value. I hypothesize that for *Schumacheria,* it may be possible to obtain a better relationship for crown diameter and dbh if regression functions are calculated separately for trees growing in different levels of sunlight (this hypothesis is being tested using additional data collected during the study). From this study, I conclude that *Schumacheria* has the most complex life history and it is inadequate to use a single equation to explain the relationship between average crown diameter and dbh.

Previous allometric studies of the relationship between crown growth and bole growth have suggested that crown dimensions are well correlated with stem dimensions (Berlyn, 1962; Baker, 1998). The surface area of a tree crown has been used to represent the photosynthetic area and in one of the first studies in tree allometry, Berlyn (1962) found it to be closely related to current stem volume growth in cottonwoods (*Populus deltoides*). Although other characteristics may demonstrate a stronger relationship to dbh, crown diameter was useful as a simple measurement to obtain an answer to the following question: within the general environmental conditions in which these pioneer species are found, what is the average density of pioneer trees that needs to be planted in order to obtain canopy closure in a stand when the planted trees are (1) 5 cm, and (2) 10 cm dbh? The average crown diameter seems to be a good parameter for obtaining a linear relationship with dbh in the pioneer species that tend to have a more flat-topped crown when growing in competition with other individuals, as in the case of *Dillenia* and *Macaranga.* The results (Table 4) indicate that it would be possible to get a closed canopy with *Macaranga* using less than 50% of the initial planting density necessary for any other species. *Macaranga* with 1000 stems/ha will close canopy at 5 cm mean dbh, whereas others at this density won't close canopy until 10 cm mean dbh.

Obtaining a closed canopy is only the first step. As presented by Parrota and others (Lugo, 1997; Parrotta, 1999; Parrotta and Knowles, 1999; Parrotta et al., 1997; Parrotta, 1995; Silver et al., 1996), the success of using pioneer species for reforestation and restoration efforts may be dependent on A) creating light conditions that eliminate weed species characteristic of degraded land but allow regeneration of native species, B) knowledge of seedling ecophysiology and ability to attract seed dispersers, C) ability to enhance the

Figure 3. *Wendlandia bicuspidata* Wright & Arn stem showing resprouting following fire damage.

nitrogen cycle of the site, D) effect of surrounding competition on tree growth, and E) use of these species as forest products. Future studies in these directions are discussed briefly below.

A) Planting density may have to be increased above the canopy closure density in order to suppress weed species such as the fern *Dicranopteris linearis* (Cohen et al., 1995). The light environment under the pioneer trees is also important for nursing the late successional species. Previous studies of autecology and seedling ecology of late successional species of the *Mesua-Shorea* community (Ashton, 1995; Ashton et al., 1995; Gunatilleke et al., 1998) demonstrate that there are clear differences in survival and growth among species related to availability of soil moisture and understory radiation regimes. Because of the variation in total crown height between the pioneer species and the variation in the height of the trees, considering crown diameter alone is not adequate to determine spacing that would later facilitate the growth of late successional species. If the pioneer trees are to be planted as a mixture, planning becomes even more complicated. Thus, to obtain a suitable light regime for effective establishment and growth of late successional species, additional characteristics such as crown height, canopy leaf density and the level of light absorption from the pioneer tree canopy need to be considered to assess the ecological suitability of combined use of these species (Menalled et al., 1998).

B) It is crucial to understand the seedling ecophysiology of these species for successful nursery establishment. Another aspect of reforestation that requires further investigation is the capacity of each species to attract seed dispersers. During this study, I observed that *Macaranga* attracted seed dispersers (especially birds) better than the other three species.

C) Many studies have shown the importance of legumes in reclamation of successionally arrested land (Ashton et al., 1997); however, none of the four species in this study is known to be nitrogen fixing. Another pioneer species of the lowland wet zone called *Trema orientalis* (L.) Blume. (Ulmaceae) belongs to the only known non-leguminous genus that can biologically fix nitrogen with rhizobia as the endophyte in root nodules (Berlyn, personal communication). This medium-sized evergreen tree grows in cleared areas and degraded sites and would be a very good candidate for restoration on dry eroded sites. Its congener *Trema micrantha* (L.) Blume., is found in the neo-tropics and has been highly recommended for site amelioration in deforested areas (Vázquez-Yanes, 1998).

D) Studies of the relationship between allometry and competition level would also be helpful in further developing a reforestation program. These pioneer species provide preliminary evidence indicating that competition has a large effect on stem and crown allometric characteristics (Goodale, unpublished data).

E) These species should be an important part of any restoration effort as the local people use them for a variety of needs (Sinharaja and Pitikelle residents, personnel communication). Wood from all four species is dried and used as fuelwood. *Wendlandia* stems are used as broomsticks, and as pole-size pillars for house building. Roof frames are constructed from *Schumacheria*. *Macaranga* leaves are used as a food wrap and timber from larger trees, with appropriate drying techniques, is used for roof ceiling frames. *Dillenia* poles are used for roof construction in small houses. Thus, it is also worthwhile to investigate how these species can be managed in agroforestry practices.

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References

Ashton, P.M.S. 1995. Seedling growth of co-occurring *Shorea* species in the simulated light environments in the rain forest. *Forest Ecology and Management* 72:1-12.

Ashton, P.M.S., C.V.S. Gunatilleke, and I.A.U.N. Gunatilleke. 1995. Seedling survival and growth of four *Shorea* species in a Sri Lankan rainforest. *Journal of Tropical Ecology* 11:263-279.

Ashton, P.M.S., S.J. Samarasinghe, I.AU.N. Gunatilleke, and C.V.S. Gunatilleke. 1997. Role of legumes in release of successionally arrested grasslands in the central hills of Sri Lanka. *Restoration Ecology* 5:36-43.

Ashton, P.M.S., C.V.S. Gunatilleke, N.D. De Zoysa, M.D. Dassanayake, I.A.U.N. Gunatilleke, and S. Wijesundera. 1997. *A field guide to the common trees and Shrubs of Sri Lanka.* WHT Publications (Pvt.) Limited, Colombo, Sri Lanka.

Baker, P. 1998. Stem and crown relations in four species from an evermoist forest in Sri Lanka. *Journal of Sustainable Forestry* 7:77-94.

Banyard, S.G. and W.D. Fernando. 1988. Sinharaja forest: monitoring changes by using aerial photographs of two different dates. *The Sri Lanka Forester* 18:101-107.

Bazzaz, F.A. 1991. Regeneration of tropical forests: physiological responses of pioneer and secondary species. In Gomez-Pompa, A., Whitmore, T.C., Hadley, M. (eds.), *Rain forest regeneration and management,* UNESCO/The Parthenon Publishing Group.

Berlyn, G.P. 1962. Some size and shape relationships between tree stems and crowns. *Iowa State Journal of Science* 37:7-15.

Brown, S. and A.E. Lugo. 1990. Tropical secondary forests. *Journal of Tropical Ecology* 6:1-32.
Budowski, G. 1965. Distribution of tropical American rainforest species in the light of successional process. *Turrialba* 15:40-42.

Clark, D.A. and D.B. Clark. 1992. Life history diversity of canopy and emergent trees in a neotropical rain forest. *Ecological Monographs* 62:315-344.

Cohen, A.L., B.M.P. Singhakumara, and P.M.S. Ashton. 1995. Releasing rain forest succession: a case study in the *Dicranopteris linearis* fernlands of Sri Lanka. *Restoration Ecology* 3:261-270.

Dallmeier, F. 1992. *Long term monitoring of biological diversity in tropical forest areas. Methods for establishment and inventory of permanent plots.* UNESCO: 9-46.

Dassanayake, M.D. and W.D. Clayton. 1996. *A revised handbook to the Flora of Ceylon. Volume X.* Oxford and IBH Publishing Co. New Delhi.

Dassanayake, M.D. and W.D. Clayton. 1997. *A revised handbook to the Flora of Ceylon. Volume XI.* Oxford and IBH Publishing Co. New Delhi.

Dassanayake, M.D. and W.D. Clayton. 1998. *A revised handbook to the Flora of Ceylon. Volume XII.* Oxford and IBH Publishing Co. New Delhi.

Davies, S.J. 1996. *The comparative ecology of Macaranga (Euphorbiaceae).* Ph.D. thesis. Harvard University. Cambridge, Massachusettes.

De Rsayro, R.A. 1954. A reconnaissance of Sinharaja rain forest. *Ceylon Forester* 1:68-74.

De Zoysa, N.D., C.V.S. Gunatilleke, and I.A.U.N. Gunatilleke. 1989. Secondary vegetation on an abandoned shifting cultivation site in the Sinharaja rainforest. *The Sri Lanka Forester* 19:3-16.

De Zoysa N.D., C.V.S. Gunatilleke, and I.A.U.N. Gunatilleke. 1991. Comparative phytosociology of natural and modified rain forest sites in Sinharaja MAB reserve in Sri Lanka. In Gómez-Pompa, A., Whitmore, T.C., and M. Hadley (eds.), *Rain forest regeneration and management,* UNESCO/The Parthenon Publishing Group.

Freund, R.J. and R.C. Littell. 2000. *SAS® system for regression.* 3rd Edition. Cary, North Carolina, USA.

Gómez-Pompa, A. and C. Vázquez-Yanes. 1981. Successional studies of a rainforest of Mexico. In: West D.C., Shugart, H.H., and D.H. Botking (eds) *Forest succession, concepts and applications.* Springer Verlag, New York.

Gregoire, T.G. and H.T. Valentine. 1995. A sampling strategy to estimate the area and perimeter of irregularly shaped planar regions. *Forest Science* 41:470-476.

Gunatilleke, C.V.S. and I.A.U.N Gunatilleke. 1981. The floristic composition of Sinharaja – a rain forest in Sri Lanka with special reference to endemics and dipterocarps. *Malay Forester* 44:386-396.

Gunatilleke, C.V.S., I.A.U.N. Gunatilleke, P.M.S. Ashton, and P.S. Ashton. 1998. Seedling growth of *Shorea* (Dipterocarpaceae) across an elevational range in Southwest Sri Lanka. *Journal of Tropical Ecology* 14:231-245.

Kuehl, R.O. 2000. *Design of experiments: statistical principles of research design and analysis.* 2nd Edition. Duxbury Press. USA.
Lugo, A.E. 1997. The apparent paradox of reestablishing species-richness on degraded lands with tree monocultures. *Forest Ecology and Management* 99:9-19.

Menalled, F.D., M.J. Kelty, and J.J. Ewel. 1998. Canopy development in tropical tree plantations: a comparison of species mixtures and monocultures. *Forest Ecology and Management* 104:249-263.

Neter, J., M.H. Kunter, C.J. Nachtsheim, and W. Wasserman. 1996. *Applied Linear Statistical Models.* The McGraw-Hill Companies, Inc. USA.

Parrotta, J.A. 1999. Productivity, nutrient cycling, and succession in single- and mixed-species plantations of *Casuarina equisetifolia, Eucalyptus robusta,* and *Luecaena leucocephala* in Puerto Rico. *Forest Ecology and Management* 124:45-77.

Parrotta, J.A. and O.H. Knowles. 1999. Restoration of tropical moist forests on bauxite-mined lands in the Brazillian Amazon. *Restoration Ecology* 7:103-116.

Parrotta, J.A., J.W. Turnbukk, and Jones. 1997. Introduction – catalizing native forest regeneration on degraded tropical lands. *Forest Ecology and Management* 99:1-7.

Parrotta, J.A. 1995. Influence of overstory composition on understory colonization by native species in plantations on a degraded tropical site. *Journal of Vegetation Science* 6:627-636.

Ray, A.A. (Ed.). 1982. *SAS users guide.* Statistical Analysis Systems Institute. Cary, North Carolina, USA.

Ricker, W.E. 1984. Computation and uses of central trend lines. *Canadian Journal of Zoology* 62:1897-1905.

Seim, E. and B.E. Sæther. 1983. On rethinking allometry: which regression model to use? *Journal of Theoretical Biology* 104: 161-8.

Silver, W.L., S. Brown, and A.E. Lugo. 1996. Effects of changes in biodiversity on ecosystem function in tropical forests. *Conservation Biology* 10:17-24.

Sokal, R.R. and F.J. Rohlf. 1995. *Biometry.* 3rd edition. W.H. Freeman and Company, New York.

Sri Barathie, K.P. 1985. Protection of Wet Zone forests. *The Sri Lanka Forester* 22: 9 - 11.

Swaine, M.D. and T.C. Whitmore. 1998. On the definition of ecological species groups in tropical rain forests. *Vegetatio* 75:81-86.

Thomas, S.C. 1996. Asymptotic height as a predictor of growth and allometric characteristics of Malaysian rain forest trees. *American Journal of Botany* 83:556-566.

Vázquez-Yanes, C. 1980. Notas sobre la autoecologia de los arboles pioneros de rapido crecimiento de La Selva tropical lliviosa. *Tropical Ecology* 21:103-112.

Vázquez-Yanes, C. 1998. *Trema micrantha* (L.) Blume (Ulmaceae): A promising neotropical tree for site amelioration of deforested land. *Agroforestry Systems* 40:97-104.

White, H. 1980. A heteroskedasticity-constant covariance matrix estimator and a direct test for heteroskedasticity. *Econometrics* 48:817-838.

Whitmore, T.C. 1978. Gaps in the forest canopy. In: Tomlinson, P.B. and Zimmermann, M.H. (eds.) *Tropical trees as living systems.*

Regeneration and the formation of pure stands of Banj Oak (*Quercus leucotrichophora* A. Camus) on abandoned terraces in the central Himalayas

Shimona Quazi, MF 2001

Introduction

Banj oak (*Quercus leucotrichophora* A. Camus) is an evergreen tree species that is heavily used in the forests of the Himalaya for fuelwood, cattle fodder and fertilizer (Mehta 1993, Chaturvedi 1989, Troup 1921). Excessive browsing and pruning of branches and shoot tips, leading to post-establishment seedling and sapling mortality, may be teh cause of low banj oak regeneration in these areas (Thadani and Ashton 1995, Singh and Singh 1987). Other suggested reasons for poor regeneration include reduced seed production, increased seed predation, and unfavorable climatic conditions (Singh and Singh 1987). A general concern also exists that the species is being replaced by chir pine trees (*Pinus roxburghii* Sarg.), which is not a preferred species in the village economies of the region.

When a seed source is available, banj seeds often germinate on both active and abandoned agricultural terraces as well as in forests. Farmers in the Kumaun Himalayas frequently leave banj oak regeneration in their fields rather than weeding it out along with other non-crop species, as it is thought to improve moisture availability for crops. In addition, the presence of banj oak in one's fields reduces travel to the forest for fuelwood and fodder collection. Banj oak seedlings growing on fields therefore have few woody competitors when these fields are let fallow. In particular, seedlings growing on the risers are not in the area of cultivation and so are less likely to be cut down at harvest time. When seedlings are released from lopping pressure by field abandonment, those on the risers have a "head start" over those growing on the flat portion of the terrace. This may explain why banj oak is often seen growing on the terrace risers on long-abandoned fields (Thadani 1999). Chir pine, on the other hand, is removed from these fields as long as they are in use, and so it cannot usually become established on these sites until after cultivation ends. Because it is shade-intolerant (Ralhan et al. 1995), chir establishment is generally expected to be low if a canopy is already present. In this way, stands dominated by banj oak may have established on the terraces.

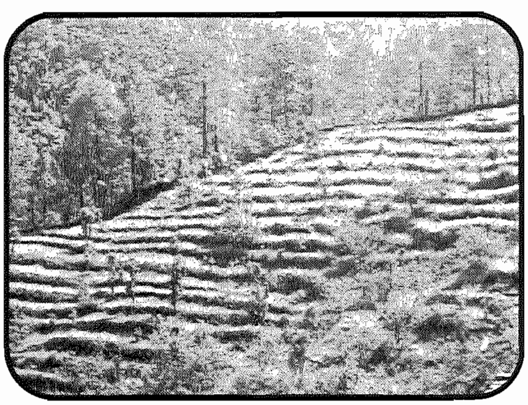
The objectives of this study were to compare banj oak and chir pine regeneration on old terraces, to identify the location on the fields (microsite) for establishment of each species, and to observe the impact of human disturbance on regeneration of each species. A chronosequence of old fields at differing levels of disturbance since the time of last cultivation were studied. The study was designed to test the hypothesis that banj oak dominates over chir pine on abandoned agricultural terraces under low to intermediate disturbance, while on highly disturbed sites I hypothesized that chir pine dominates. The study was conducted in and around the village of Sitla in the Nainital district of Kumaun, Uttaranchal in India.

Study Site

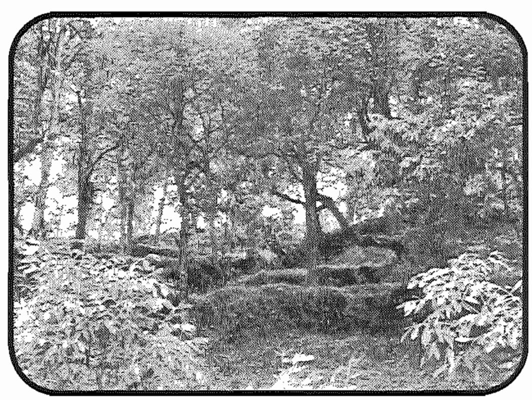
Kumaun shares borders with Tibet and Nepal (along the Kali River) and is bounded to the south by the Sivalik Hills. Nainital lies in the Lesser Himalaya belt. The soils are derived from slate, sandstone and limestone (Singh 1983) and are neutral to alkaline in pH; this is also the region in which much of the forest of the Himalayas is located. The altitude ranges from 1000 to 3000 m and the climate is seasonal, with winter temperatures from 3° to 10°C (December to February) and summer temperatures from 17° to 26°C (March to June). The annual rainfall is 800 to 1200 mm, most of which occurs during the monsoon season from late June to September. The rest of the annual precipitation occurs as snow. Forests in this region are categorized as Himalayan moist temperate forests.

Methods

Based on information from interviews with local landowners and residents, sixteen abandoned terraced fields of similar altitude and aspect were selected. The fields chosen were within a radius of about 10 km at an average elevation of 1900 m (range 400 m), and were almost all directly north-facing. The crops that had been planted on the fields studied were primarily wheat, potatoes or fruit. These fields were placed into 3 categories of time since abandonment: 0 to 20 years, 25 to 50 years, and more than 50 years (Table 1). Fields were selected so that each fallow period had about the same number of fields under one of two disturbance regimes, high and



Banj oak regeneration on young terrace



Abandoned terrace after 100-150 years of regeneration

Table 1: Summary of sites

Name of Site	Years since abandonment	Disturbance regime and type	Previous use/crop
Sunkhiya	4	low- some grazing	fruit orchard
Simayila	5	low- some lopping	wheat
Janmilen	8	high- grazed, fuel gathering	mushrooms
Sushil	10	low- protected by owner	fuel / fodder
Nepali	10-17	high- grazed	potatoes
Odhakhan	15	high- grazed	wheat
Rajesh	15	low- some grazing	fruit orchard
Sitla goar	25	low- some grazing	wheat
Saji	25-35	low- some grazing	wheat
Somerset	30-40	low- protected by owner	old coppice
Bhulmuriya	30	high- protected forest	pulses/fodder
Bhandari	60	high- grazed, fuel gathering	unknown
Sattoli	60	high- grazed	wheat
Natuakhan	100-150	high- annual litter clearing	unknown
Galkatta-a	150	low- protected forest	unknown
Galkatta-b	150	low- protected forest	unknown

low. Highly disturbed areas were identified by poor tree growth form, grazed or lopped stems, and the presence of fuel collectors, cattle, hoof marks, or dung. Annual litter clearing was also characterized as high disturbance. Low disturbance was defined by the comparatively low level or complete absence of the above features.

In each field, between three and eight 10-meter transects were randomly located along the risers of the terraces. The sampling units comprised the whole riser and flat part of each stretch of terrace, producing a total of 86 variable-area plots. The area of each plot was determined by measuring the widths at the two ends and at the center of the flat or riser, and then using the average width multiplied by the fixed transect length of 10 m. Total plot area was calculated as the area of the flat plus the surface area of the riser.

The two woody species considered in this analysis, *Quercus leucotrichophora* (banj oak) and *Pinus roxburghii* (chir pine), are among the most important tree species in this area (as measured after Brower, Zar and von Ende 1998). Measurements were made of height, root collar diameter of seedling sprout or basal diameter of stump sprout. The origin of the regeneration (seed, root sucker or stump sprout) and the number of sprouts were noted.

Square-root transformed data was used for stem densities, and log-transformed data for height and diameter measurements (after Sokal and Rohlf 1995). A complete analysis of variance was performed using SAS software (SAS Institute 2000) to test the relationships between species, disturbance, regeneration microsite, and time since field abandonment. An adjusted 2-way Tukey-Kramer test for multiple comparisons was then used to test treatment interactions at a significance threshold of $\alpha=0.05$. The calculated means, 95% confidence intervals and standard deviations of the means were rescaled to the original units for graphical purposes.

Figure 1a: Species stem densities with variation in terrace microsite

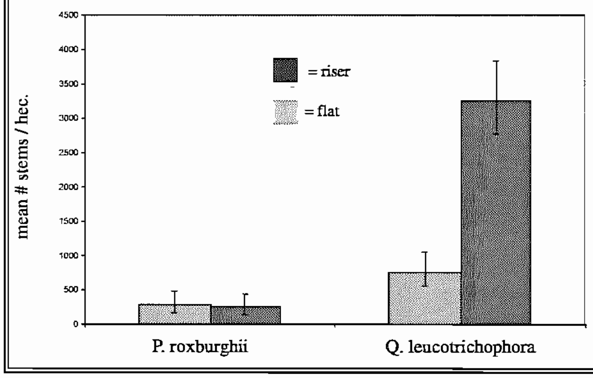


Figure 1b: Species mean height with variation in terrace microsite

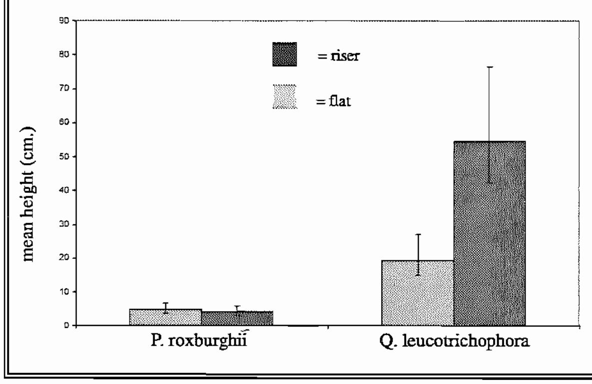
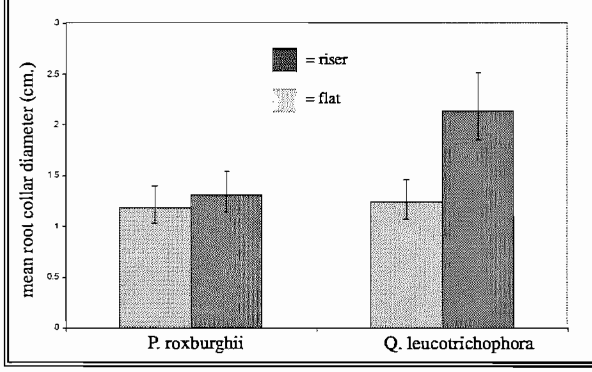


Figure 1c: Species mean root collar diameter with variation in terrace microsite



Results

The mean stem density over all sites varied significantly between chir pine and banj oak ($P<0.0001$); chir pine occurred at an average of about 1200 stems/ ha while banj oak were found at about 3000 stems/ ha. These densities are higher than other estimates for these species for mixed forests in the area that are not on agricultural terraces (Saxena and Singh 1982), which is consistent with the findings of Thadani (1999). Mean height was significantly lower in chir pine overall (35.72 cm compared to 151.19 cm in banj oak; $P<0.0001$), as was mean stem diameter at root collar (1.34 cm in chir pine versus 3.23 cm in banj oak; $P=0.0013$). Significant interactions were found between species and microsite, and species and disturbance for stem density ($P<0.0001$ and $P=0.0002$ respectively), tree height ($P=0.0318$ and $P<0.0001$) and root collar diameter ($P=0.0539$ and $P=0.0038$). The interaction between species and time since abandonment was also significant in terms of its effect on height and diameter ($P=0.0012$ and $P=0.0033$). Time since abandonment had a significant effect on overall stem density of both species ($P=0.0013$).

The species and regeneration microsite interaction was significant for all three response variables measured (density, height, and root collar diameter). The Tukey-Kramer test for multiple comparisons showed that banj oak growing on the terrace risers had sig-

Figure 2a:Species stem densities with varying disturbance levels

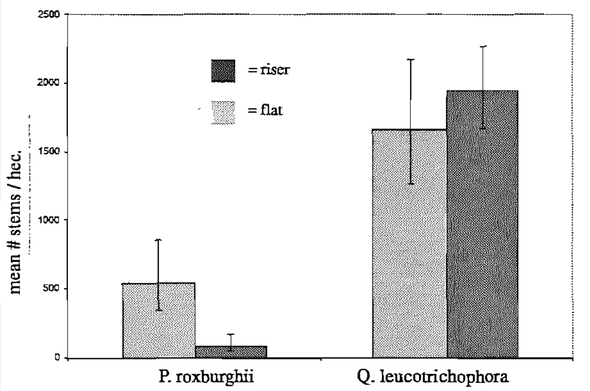


Figure 2b: Species mean heights with varying disturbance levels

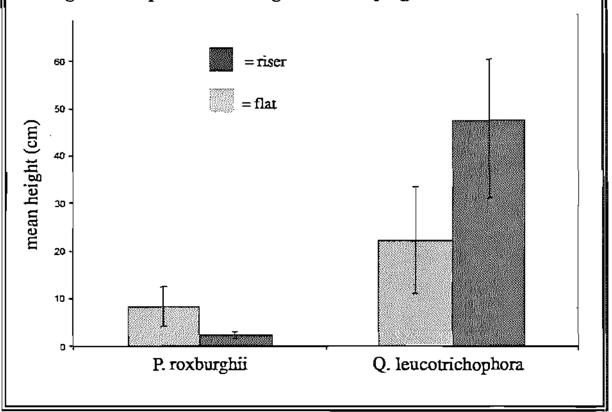
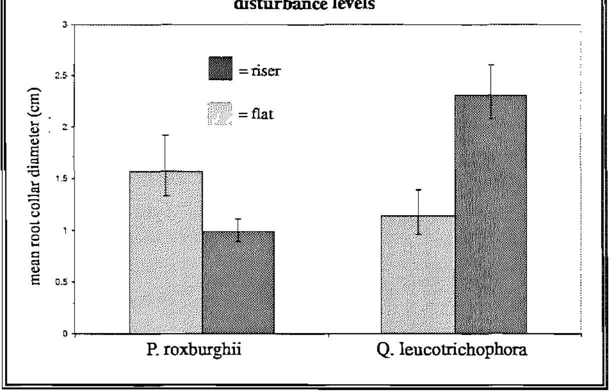


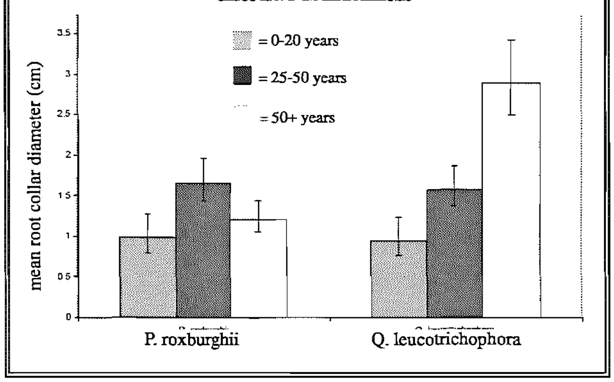
Figure 2c: Species mean root collar diameter with varying disturbance levels



nificantly higher stem density (P<0.0001), height (P=0.0613), and diameter (P=0.0548) than banj oak growing on the flat part of the terrace. Banj oak on risers also had significantly higher stem density (P<0.0001, P<0.0001), height (P<0.0001, P<0.0001), and diameter (P=0.00324, P<0.0001) than chir pine growing on the flats and risers, repsectively. Microsite variation did not significantly effect the growth of chir pine, which occurred on flats and risers alike in equal density (Fig. 1a-c).

Disturbance showed a significant species interaction for density (P=0.0002). Although chir pine has greater mean stem density under high disturbance and banj oak has higher mean density under low disturbance, the differences were not significant (Fig. 2a).

Figure 3: Species mean root collar diameter with increased time since field abandonment



Chir pine were significantly taller on highly disturbed sites than on less disturbed sites (P=0.0156), due to higher light availability, while banj oak height was not affected by disturbance level (Fig. 2b). Banj diameter was negatively correlated with level of disturbance, while chir pine diameter was not affected (Fig. 2c).

Time since field abandonment had no significant effect on stem density of either species. Comparisons across pairs of time categories indicated significant increases in banj oak height (P=0.0967 and P<0.0001) and diameter (P=0.0015 and P=0.0706) with time; chir pine showed no significant difference in height or diameter across the old field chronosequence (Fig. 3).

Discussion

Clear response differences between banj oak and chir pine were observed for both microsite and disturbance regime. Banj oak grew predominantly on the risers of the terraces, while chir pine was found uniformly on both risers and flats. Banj oak growing on the flats were consistently lower in height and diameter than those on the risers. This may be attributable both to the earlier establishment of banj on the risers during cultivation, as well as to the greater accessibility of the terrace flats, both to livestock and to people collecting fodder and fuelwood. On the other hand, microsite did not affect chir pine height, diameter, or density because it is selectively removed from all parts of the terrace until the cessation of agriculture (Thadani 1999, pers. obs). After field abandonment, it is neither used by people nor palatable to animals and so chir is able to establish simultaneously on all parts of the field. Variability of mean height and diameter was also much higher in banj oak than in chir pine, which may be explained by continued grazing and branch pruning of the former.

Banj oak stem density was higher than that of chir pine regardless of disturbance regime, in contrast to non-terraced areas where chir pine is believed to dominate disturbed sites (Singh and Singh 1992, Champion and Seth 1968). Disturbance intensity did not significantly affect stem density in either species, and banj oak density was high even under conditions of high disturbance and therefore high light availability. This supports Thadani and Ashton's findings (1995) that low light conditions actually inhibit banj oak survival rates, while moderate shade and intermediate disturbance promote banj establishment; banj oak seedlings are not as highly shade-tolerant as previously thought.

Growth form of banj oak, however, was negatively affected by disturbance; banj oak showed reduced diameter growth under high disturbance due to chronic browsing and branch pruning. Height growth, however, was not affected, producing spindly trees.

Conversely, chir pine is considered a shade-intolerant species that is not browsed or pruned, and exhibited a strong positive height growth response to high disturbance, while its diameter growth was unaffected. It is important to note that the disturbance level has different implications for each of the two species; not only does it impact light availability for both species, but it also indicates removal of living biomass in the case of banj oak. The differences in growth form under varying disturbance levels are thus not only due to inherent growth characteristics but also to anthropogenic processes.

Banj oak showed significant increases in height and diameter with increased fallow period, but chir pine showed no significant difference. I suspect that chir pine regeneration is probably about the same age in both old and newly abandoned fields; due to the inadequate light available to pines germinating under an oak canopy, any pine regeneration is most likely new opportunistic seedlings that germinated in gaps. Older chir pine regeneration would have been suppressed by the oaks and died off without reaching any appreciable size. Banj oak, however, is moderately shade-tolerant and continues to grow in size uniformly in all categories, even the older, shadier sites, so that tree size increases with age of field.

Unexpectedly, although time since abandonment had a significant effect on overall stem density, differences in stem density observed across the chronosequence of fields were not significant for either species. This is in strong contrast to comparably long-term chronosequence studies on abandoned fields, where stem density is found to first increase during a period of stand initiation and then decrease over time, following the Oliver and Larson pattern of forest development (Kappelle et al. 1996, Oliver and Larson 1996, Saldarriaga et al. 1988). This may be due to inappropriate site selection for the chronosequence due to an inaccurate site history, or other factors such as distance from seed source or former land use (Kappelle et al. 1996). However, it may reflect a true pattern of inadequate stocking in old fields that should be further investigated.

In conclusion, the data does not support the hypothesis that banj oak dominates on abandoned agricultural terraces under low to intermediate disturbance, while chir pine dominates on highly disturbed fields. Instead, in agreement with previous findings about its light and disturbance requirements, banj oak dominated under both disturbance regimes, significantly on the terrace risers. This confirms that banj oak established earlier on the risers, i.e. during cultivation, and in this way escaped browsing and pruning that began at field abandonment. Additionally, stem density of oaks is the same across time categories; this indicates that seedling regeneration of banj oak may be low on recently abandoned fields due to the greater distance from seed source than in other banj oak forests, or due to other differential conditions in soil, light or moisture. Low regeneration may not be a cause for concern if banj stems established on the terrace risers have higher survivorship than seedlings in non-terraced areas. However, given that chronic disturbance levels may be changing in some areas, active management of fallow areas for banj oak should be considered if other alternatives for fuelwood and fodder cannot be utilized.

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References

Brower J.E., J. H. Zar, C.N. von Ende. 1998. Field and laboratory methods for general ecology 4th Ed. McGraw-Hill, Boston, MA.

Champion, H.G. and S.K. Seth. 1968a. A revised survey of the forest types of India. New Delhi: Government of India Publications Division.

Chaturvedi, A.N. 1983. In J.S. Singh (ed). Environmental regeneration in the Himalaya: concepts and strategies. Gyanodaya Prakashan and the Central Himalayan Environmental Association, New Delhi.

Kapelle, M., T. Geuze, M.E. Leal and A.M. Cleef. 1996. Successional age and forest structure in a Costa Rican upper montane Quercus forest. Journal of Tropical Ecology 12:681-698.

Mehta, J.S. 1993. Ecological history of ban oak in Uttarkhand. In Rawat, A.S. (ed) Indian forestry: a perspective. New Delhi: Indus Publishing Company.

Oliver, C.D. and B.C. Larson. 1996. Forest Stand Dynamics, Update Ed. John Wiley and Sons, New York.

Ralhan. P.K., R.K. Khanna, S.P. Singh and J.S.Singh. 1995. Phenological characteristics of the tree layer of Kumaun Himalayan forests. Vegetatio 60(2):91-101.

Saldarriaga, J.G., D.C. West, M.L. Tharp, and C. Uhl. 1988. Long-term chronosequence of forest succession in the Upper Rio Negro of Colombia and Venezuela. Journal of Ecology 76(4):938-958.

Saxena, A.K. and Singh S.P. 1982. A phytosociological analysis of woody species in forest communities of a part of Kumaun Himalaya. Vegetatio 50:3-22.

Singh, J.S.and S.P. Singh. 1992. Forests of the Himalaya: Structure, functionaing and impacts of man. Gyanodaya Prakashan, New Delhi.

Singh, J.S. and S.P. Singh. 1987. Forest vegetation of the Himalaya. Botanical Review 53:80-192.

Sokal, R.R. and F.J. Rohlf. Biometry 3rd Ed. W.H. Freeman and Company, New York.

Thadani, R.T. 1999. Disturbance, microclimate and the competitive dynamics of tree seedlings in banj oak (Quercus leucotrichophora) forests in the Central Himalaya, India. PhD. Thesis, Yale University.

Thadani, R.T. and P.M.S. Ashton. 1995. Regeneration of banj oak (Quercus leucotrichophora A. Camus) in the Central Himalaya. Forest Ecology and Management 78(1-3):217-224.

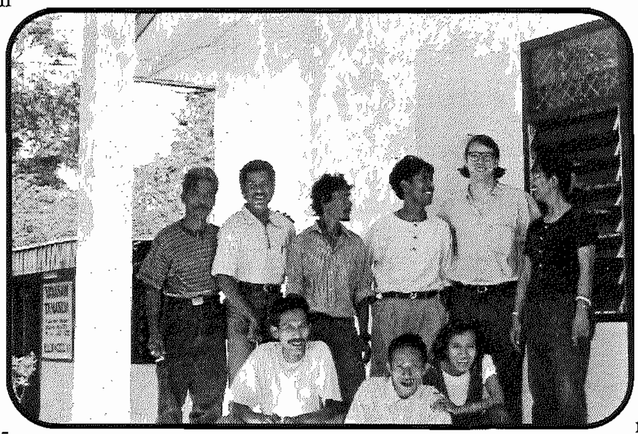
Troup, R.S. 1921. The silviculture of Indian trees, Vol. III. Clarendon Press, Oxford.

El Niño and economic crisis in rural Indonesia: A case study of collaboration in resource management problems

Christian C. Lentz, MESc 2001

Introduction

Collaboration literally means to mix labor in pursuit of a common goal. In the context of natural resource management, collaboration signifies an inclusive means of improving the sustainability of resource use and community participation. Problem identification and investigation constitute early steps that provide a point of entry to someone interested in engaging in collaborative research. Conducting research as a collaborative process may improve interdisciplinary analysis, span administrative boundaries, and facilitate understanding among stakeholders. This paper represents a reflection on the experiences of one collaborative research effort in Indonesia. Lessons learned may provide guidance for future researchers as to how to engage in collaborative processes when addressing interactions between people and nature.



Christian Lentz with collaborators from Yayasan Tananua, East Sumba, Indonesia

Recent literature on collaboration has grown out of a recognition that conflict often accompanies conservation when decisions do not reflect the interests of all stakeholders (Wondolleck and Yaffee 2000; Lee 1993). Conflict is not always negative or something to be avoided; on the contrary, it has the benefit of calling attention to conditions in need of change (Fisher and Ury 1991). Rather than blame conflict itself as a reason for failure, these authors instead point to confrontational approaches such as litigation as contributing to decisions characterized by ineffective solutions and biased outcomes. In Indonesia, a classic case is the Forest Ministry's attempt to reforest grassland areas considered by the state to be protected forest, yet used by communities as grazing land. The disputed tenure often means that reforestation plots and tree seedlings are burned during grassland fires (Dove 1986).

In the late 1980's and early 1990's, collaboration gained recognition as practitioners and scholars recognized a need to develop new decision making processes geared toward reaching mutually acceptable solutions. An early scholar and authority on the subject, Barbara Gray, defined collaboration as "a process through which parties who see different aspects of a problem can constructively explore their differences and search for solutions that go beyond their own limited vision of what is possible" (Gray 1989). By addressing the different perspectives from which collaborators approach a common problem, these parties are able to engage in a process of learning not only about the problem, but also about one another's priorities and values.

In a recent work written for practitioners in the field of natural resource management, Wondolleck and Yaffee (2000) identify a series of uses and values of the collaborative approach to decision making. These include building understanding through information exchange, improving decision making on common problems, coordinating cross-boundary activities, fostering joint management, and drawing on an expanded set of institutional resources. In addition, these approaches can aid in developing the capacity of agencies, communities, and organizations to deal with future problems. Of these uses and values, I will focus on information exchange and its relation to improving stakeholder understanding because students and researchers can play a significant role in facilitating the flow of data and analysis.

Case Study:

Indonesian Smallholders, El Niño, and Economic Shock

During the late 1990's, Indonesia experienced a political transition, an economic shock, and a severe drought. The global ramifications of President Suharto's resignation, the East Asian financial crisis, and the El Niño drought were widely discussed in the popular media, yet the voices and perspectives of the majority of Indonesia's population-- smallholding farmers-- rarely received notice. The handful of research on the effects of the economic shock on small farmers produced widely divergent findings regarding the effects of farm commodity price changes on farmers (Hill 1999; Fox 2000). Furthermore, many approaches tended to look only at economic shock or only at drought, neglecting the connections and feedbacks between the social and natural phenomena. Such narrowly focused approaches contrast sharply with the way in which these problems were (and still are) experienced by Indonesian farmers and their families.

I chose to research the broad problems of economic shock, drought, and consequent changes in rural welfare through an in-depth study of smallholding farmers and pastoralists in East Sumba, Indonesia. My study explored farmers' resilience in the face of disturbance originating in economic shock and drought. While disturbance in the form of rapid social and ecological change occurred at the global level, resilience – the ability and means of responding to such change – occurred in and among communities at the local level. This complex multi-scale problem called for a collaborative research approach that could draw on the strengths of organizations working internationally, regionally, and locally.

At the international level, researchers at the Center for International Forestry Research (CIFOR) had published several influential papers (Sunderlin et al 2000; Sunderlin 1999) on the effects of economic shock on rural welfare and forest cover. Their research methodology and survey questionnaires formed the basis for my own inquiry. At the regional level, the Nusa Tenggara Community Development Consortium (NTCDC) spanned an umbrella network of collaborating governmental, non-governmental, university, and community organizations (Fisher et al 1999), several of which provided strong local support. For example, Team Koppesda, an NGO that researches problems of community resource management around priority conservation areas, provided logistical support and guidance. Yayasan Tananua, a community development NGO with extensive experience in the communities I studied, assisted with establishing local contacts, advising on substantive issues, and providing me with an extremely capable research assistant.

The interdisciplinary nature of this research called for the use of multiple methods. Early in the research, semi-structured interviews with farmer groups produced qualitative information on the severity and duration of problems associated with drought and economic shock. Participant observation through activities such as fishing, threshing rice, and collecting forest tubers enabled me to ask detailed questions about resource harvest and management and, additionally, to establish trust with community leaders. Formal interviews incorporating household surveys produced both qualitative and quantitative data about crop yields and commodity prices over time. Open-ended interviews with key informants allowed me to clarify complex issues such as the cultural basis of forest management practices. Techniques drawn from participatory rural appraisal (PRA: Chambers 1994) produced rich data on seasonal change in household harvest cycles, labor allocation, and food consumption.

Discussion

The diverse partners assembled in this research effort had a variety of reasons for being interested in the outcome of this study. Researchers at CIFOR wanted to compare it to their earlier work in the province of East Nusa Tenggara, an area of Indonesia hit hard by the drought and economic shock. The NTCDC, Team Koppesda, and Yayasan Tananua were interested in learning about changes in community welfare as well as receiving evaluation and feedback on current programs. The communities themselves were interested in finding solutions to a locust outbreak that may have been caused by the El Niño drought (Lecoq 2000). Responding to each of these interests required the preparation of multiple reports in order to fulfill obligations to each party.

Fortunately, I was able to build on relationships developed during a 1997 participatory protected area inquiry in East Sumba (Fisher et al 1999; Lentz, 1998); this experience had already established trust with key stakeholders both in local organizations and in village communities. Daily collaboration with my talented and experienced research assistant, Umbu Hilu, reinforced the trusting relationship I had with his organization (Tananua) and with the communities in which we worked. Despite a challenging environment, Hilu's proficiency in Kambera (the local language), knowledge of the agro-ecological terrain, and ability to bridge cultural distance enhanced our ability to conduct the research. Hilu's experience contributed enormously to adjusting the methods of inquiry to best fit the local socio-economic and cultural conditions. Futhermore, our mutual understanding and pursuit of a common goal helped to develop lasting relationships with local leaders and farmers.

Flexibility in the implementation of a collaborative arrangement is widely recognized as essential to its success. Both the research schedule and the location of the sites were by necessity fluid, while following my meticulously planned timeline was impossible. Adhering to a rigidly constructed research plan risked alienating my institutional collaborators and offending community members. The suitability of planned research sites could not be fully known ahead of time; consequently I chose and re-chose the villages that were ultimately included in the study.

While maintaining flexibility aided in building relationships with informants and partners, it also limited the depth of the research in other ways. Communicating my research goals and agenda to local organizations, leveling perceptions and planning the cooperative endeavor meant that I spent less time in the field talking with farmers. Fulfilling my obligations to local organizations and leaders conflicted with my research agenda; this dilemma forced me to cancel engagements with other partners towards the end of the research. Indeed, collaborative research efforts often require years to plan and implement (Grove and Burch 1997; Fisher et al 1999).

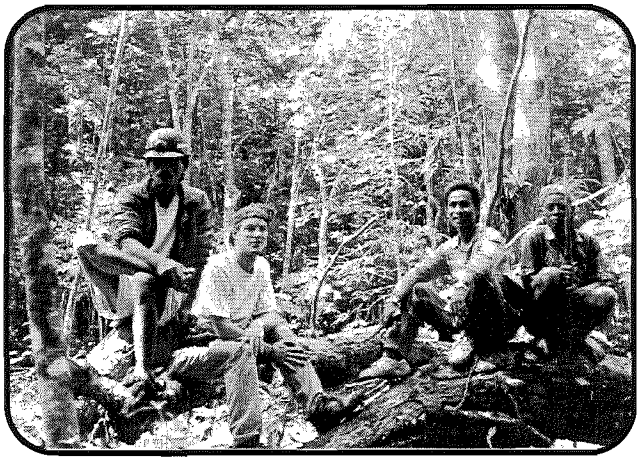
Collaborating with a female research assistant was not an available option for me; however, such a partnership could have increased the validity and depth of the data Hilu and I collected. In East Sumba, as in many developing nations (Escobar 1995), women play a large role in the management of natural resources, particularly in the collection and preparation of edible foodstuffs. In spite of the obvious significance of female informants to my research, I experienced enormous difficulty in eliciting information from female members of households. Despite efforts to communicate to village officials and male heads of households the need to include women in formal interviews and surveys, cultural and domestic factors hampered the collection of reliable, gendered data. In the local culture, men represent the public head of household while private household decisions are made jointly. The women were most available for answering questions while cooking; however, the kitchen was not an acceptable place for men. Furthermore, as honored guests in each home we visited, my assistant and I were served coffee and hot meals, the preparation of which drew women into the kitchen and away from the guests. A female research assistant could have aided significantly in overcoming these problems.

While helpful in sketching the need and potential benefits of a collaborative resource management approach, the literature on the subject presents several problems, notably contextual bias and underlying assumptions. First, much of the current literature draws on experience gathered from domestic (US) contexts. For example, Kai Lee (1993) writes eloquently of the compass of science and the gyroscope of bounded decision making processes based on his experience in managing the salmon populations of the Columbia River in the Pacific Northwest. Yet his reliance on domestic case studies limits the applicability of his work in developing nations, particularly because of the differential strength and accountability of government institutions. Moreover, the US has a strong civil society that allows for dissenting voices to be heard without fear of reprisal; such may not be the case elsewhere.

Secondly, many of these writers make assumptions about stakeholders' willingness to reduce uncertainty and their desire to work with one another. Such willingness and desire may not be evident in all resource management contexts, as Thompson, Warburton, and Hatley discuss (1986). For example, although government agencies often have overlapping mandates that appear conducive to collaboration, their budgetary allocations may rest on their ability to defend and maintain their "turf." In Sumba, there is no single standard government map: each government agency has produced its own map, many of which are contradictory. A suggestion to produce a map jointly could threaten the job safety of cartographers within each agency.

Conclusions

This study illustrates that resource-related problems resist clear disciplinary and spatial boundaries. Collaborative approaches can provide a perspective that draws on multiple disciplines and scales, in which partners with varied experience enable the individual researcher to draw on an organization's comparative expertise. International organizations like CIFOR have the institutional capac-



Taking a break en route to the summit of Mount Wanggameti

ity to address global and regional phenomena such as climatic peturbation and rapid socio-economic change. Local NGOs such as Yayasan Tananua have an intimate understanding of cultural landscapes and ecological contexts. Regional organizations such as the NTCDC can help to bridge the conceptual and spatial distance between international and local partners. The researcher becomes a communicator between these organizations with the opportunity to assess linkages across spatial scales.

Working with multiple partners requires an investment of time, particularly during the planning and follow-up phases. In a study of limited duration (such as a summer research project), a commitment to collaboration may reduce time allocated to addressing research questions. Yet in addition to improving data collection and analysis, collaboration may yield unanticipated benefits by encouraging parties to broaden their perspectives. Organizations tend to adhere to specialized mandates that restrict the scope of their activities as well as their ability to find solutions to common problems. Collaborating in a joint fact-finding endeavor can reduce uncertainty arising from divergent perspectives and strengthen interpersonal relationships (Wondolleck and Yaffee 2000). Identifying issues of common concern and learning about them collaboratively can therefore lead to the formation of fruitful long-term partnerships.

Acknowledgements

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References

Chambers, Robert. 1994. "The Origins and Practice of Participatory Rural Appraisal." *World Development* 22 (953-969).

Dove, Michael R. 1986. "The Practical Reason of Weeds in Indonesia: Peasant vs. State Views of *Imperata* and *Chromoleana*." *Human Ecology* 14 (163-189).

Escobar, Arturo. 1995. *Encountering Development: The Making and Unmaking of the Third World.* Princeton University Press: Princeton, NJ.

Fisher, Larry, Ilya Moeliono, and Stefan Wodicka. 1999. "Multiple Site Lessons in Conflict Resolution in the Nusa Tenggara Uplands, Indonesia." In D. Buckles, ed., *Cultivating Peace: Conflict and Resolution in Natural Resource Management.* IDRC / World Bank: Washington, D.C.

Fisher, R. and W. Ury. 1991. *Getting to Yes: Negotiating Agreement without Giving In.* Penguin Books: New York.

Fox, James. 2000. "The Impact of the 1997-98 El Niño on Indonesia." In Richard Grove and John Chappell, eds. *El Niño-- History and Crisis.* Proceedings of a Symposium at the Australian National University, 27 February 1998. Galley Proofs.

Gray, Barbara. 1989. *Collaborating: Finding Common Ground for Multiparty Problems.* Josey-Bass Publishers, San Francisco.

Grove, Morgan and William Burch. 1997. "A Social Ecology Approach and Applications of Urban Ecosystem Analyses: A Case Study of Baltimore, Maryland." *Urban Ecosystems* (1) 259-275.

Hill, Hal. 1999. *The Indonesian Economy in Crisis.* Allen and Unwin: St. Leonards, Australia.

Lee, Kai. 1993. *Compass and Gyroscope.* Island Press, Washington, D.C.

Lecoq, Michel. 2000. "Outbreaks of the Oriental Migratory Locust in Indonesia." CIRAD: Montpellier, France.

Lentz, Christian C., Larry Fisher, Agus Mulyana. 1998. "Natural Resources Decision Making in Wanggameti: A Collaborative Research and Convening Process." Paper presented at the International Association for the Study of Common Property, Vancouver, BC, Canada.

Sunderlin, William D., Ida Aju Pradnja Resosudarmo, Edy Rianto, and Arid Angelsen. 2000. "The Effect of Indonesia's Economic Crisis on Small Farmers and Natural Forest Cover in the Outer Islands." CIFOR Occasional Paper, Bogor, Indonesia.

Sunderlin, William D. 1999. "Between Danger and Opportunity: Indonesia and Forests in an Era of Economic Crisis and Political Change." *Society and Natural Resources* 12: 559-570.

Thompson, M., M. Warburton, and T. Hatley. 1986. *Uncertainty on a Himalayan Scale: An Institutional Theory of Environmental Perception and a Strategic Framework for the Sustainable Development of the Himalaya.* Milton Ash Editions: London.

Wondolleck, Julia M. and Steven L. Yaffee. 2000. *Making Collaboration Work: Lessons from Innovation in Natural Resource Management.* Island Press, Washington, D.C.

Yaffee, Steven L. 1994. "The Northern Spotted Owl: An Indicator of the Importance of Socio-Political Context." In Tim W. Clark, Richard P. Reading, and Alice L. Clarke, eds. *Endangered Species Recovery: Finding the Lessons, Improving the Process.* Island Press: Washington, D.C.

The extraction of the non-timber forest product *mai hom* (*Aquilaria crassna*) in northeast Thailand

Christie M. Young, MFS 2000

Introduction

The agarwood tree, *Aquilaria crassna* (Thymelaeaceae), is a tropical mid-canopy tree of Southeast Asia. From the Indian subcontinent to the islands of Indonesia, this tree and other members of the *Aquilaria* genus yield a lucrative non-timber forest product (NTFP) created by a fungal infection of the heartwood (Oyen and Dung 1999, Chakrabarty et al. 1994, Burkhill 1935). The introduction of an unidentified pathological fungus triggers the production of a resin which saturates the phloem, creating a blackened aromatic wood that is highly profitable in the international market (Jalaluddin 1977). Fetching prices up to thousands of dollars per kilogram, *mai hom*, the resin-saturated wood, is utilized in religious ceremonies, for medicinal products, and in the fabrication of incense (Burkhill 1935).

Spurred by heavy demand and the lucrative profit obtained from the harvesting of *mai hom*, illegal and indiscriminate extraction of this non-timber forest product is practiced throughout Southeast Asia. *Mai hom* collectors carve out modest to large portions of aromatic wood from the bole of infected trees, sometimes to the point of rendering mechanical damage (Figure 1). Collectors also hack out portions of uninfected trees with the hope that this damage will facilitate the introduction of the fungal disease which promotes the production of the aromatic resin. Except in extreme cases or when trees are felled, *Aquilaria* trees are not killed by *mai hom* collection.

This paper aims to describe the ecological effects of *mai hom* collection on the population of *Aquilaria crassna* in Khao Yai National Park. While the sustainable extraction of non-timber forest products has been presented as an economic alternative to deforestation, the sustainability of *mai hom* extraction has received little attention. Proponents of NTFP extraction contend that when properly managed, species can serve as renewable resources that can be harvested without long-term damage to the ecosystem, lending economic value to intact forests (Plotkin and Famolare 1992). However, the sustainability of NTFP extraction is questionable if social and ecological parameters are not continually evaluated. Peters (1994) suggests an overall strategy for sustainably managing NTFPs which is firmly grounded in ecology and relies on continually monitoring the ecological response of the species to harvesting. Special emphasis is placed upon the population's size class distribution to assess regeneration and recruitment in order to interpret the population's response to harvesting and ensure its long-term health.

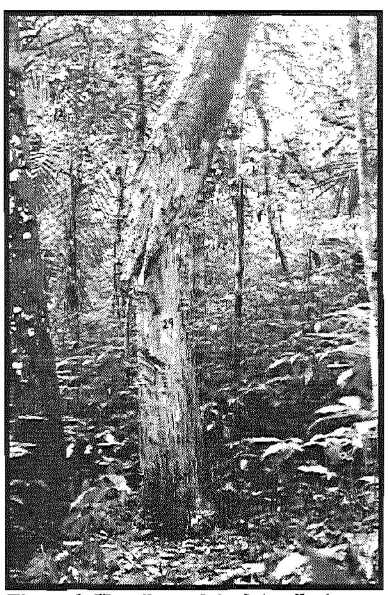


Figure 1. Heavily exploited *Aquilaria crassna* tree. Poachers have extracted enough *mai hom* from the bole of this tree to render mechanical damage. *Photo:* W. Brockelman

The current and historic extraction of *mai hom* has left some populations of *Aquilaria* vulnerable to extinction (Mittelman et al. 1997). *Mai hom* collection is practiced in forests where *Aquilaria* populations occur in low densities. Throughout Southeast Asia, studies have recorded populations of less than one tree per hectare and as low as one tree per eight hectares (Paoli in press, La Frankie 1994). The rampant extraction and low density of *Aquilaria* create a lethal combination with the potential for species extinction. Following the methodology of Peters (1994), this paper presents an ecological snapshot of two populations of *Aquilaria crassna* in Khao Yai National Park, providing baseline information which can be used in the design of sustainable management plans for *mai hom* extraction.

Site Description

Located 238 km northeast of Bangkok, Khao Yai National Park contains a wide diversity of plant and animal species within a 2168 km^2 area dominated by seasonal wet evergreen forest (Royal Forest Department 1990). Khao Yai National Park is located between 14° 05' and 14° 15' North latitude and 101° 05' and 101° 50' East longitude. Elevation ranges from 250 m to 1351 m above sea level over a generally mountainous topography (Royal Forest Department 1985). The majority of the 2270 mm of annual precipitation falls during the monsoon season from May to October with low rainfall during the dry months from December to January. The average annual temperature is 23° C and the average relative humidity is 86% (Royal Forest Department 1990). The majority of soils in this area are shallow red-yellow Podzolic soils formed from colluvium and residuum. They are moderate to well-drained with moderate to low fertility, and are highly susceptible to erosion (Royal Forest Department 1985).

Research Study Sites

Two sites within Khao Yai National Park were chosen for studying the effects of *mai hom* extraction on *Aquilaria crassna* populations: Mo Singto and Khlong Sai (Figure 2). Mo Singto is an approximately 29-ha demographic tree plot created for the long-term study of white-handed gibbons (*Hylobates lar*) (Brockelman and Charoenchai 1999). Within the plot, all woody plants greater than or equal to 10 cm diameter at breast height (1.3 m) have been tagged, mapped, measured, and identified following the protocol of the Smithsonian Institution's Center for Tropical Forest Science (Condit 1998). Since the Mo Singto plot was created in 1996, *mai hom* poaching has virtually ceased within its bounds.

The second study area, Khlong Sai, is located approximately 3 km North of Mo Singto in a drier, lower-canopied, single to multiple strata evergreen forest. The 8.8-ha Khlong Sai plot was created during the course of this study to identify, measure, and map only *Aquilaria crassna* individuals. Of the plot's 8.8-ha, 4.4 ha have been mapped. The Khlong Sai plot is located in a forest with currently heavy levels of *mai hom* extraction; historical extraction is believed to have been moderate to low.

Methods

Forest Inventory

A basic forest inventory was conducted for all *Aquilaria crassna* stems greater than or equal to 10 cm dbh to obtain size class distributions for the two sites. All individuals were measured for height, dbh, and *mai hom* exploitation level. The presence of ants was noted and fruit production was measured by sampling 50 x 50 cm plots around fruiting trees. Following the methodology of Nan and Brockelman (1998), stems were mapped by one of three methods: 1) the angle and distance from a known point, 2) angles from two known points, or 3) distances from two known points. XY coordinates were entered into Microsoft Excel and geo-referenced in ArcView (GIS).

Figure 2: Forest in Khao Yai National Park which contains the Khlong Sai study site. This forest is smaller in stature and drier than the CTFS Khao Yai Forest Dynamics Plot.

Regeneration Plots

Regeneration and recruitment of *Aquilaria crassna* was measured in each site through the placement of 30 transects (10 x 5 m) in randomly selected 20 x 20 m quadrats. All mapped quadrats were stratified into two groups depending on *Aquilaria crassna* density. In this frequency count, *Aquilaria crassna* stems less than 10 cm dbh were placed into height categories (0-50 cm, 50-100cm, 100-150cm, 150-200cm); for trees taller than 200 cm, two dbh size classes (1-5 cm and 5-10cm) were used to group individuals.

Extraction

Since *mai hom* collectors carve varying amounts of wood from the bole, four damage classes were created to categorize the extent of extraction—nil, medium, high, and cut. The *nil* category represented zero to insignificant levels of *mai hom* collection. The *medium* category represented a *mai hom* extraction of up to 1/4 of the circumference of the bole. In the *high* category, extractions were greater than 1/4 of the circumference of the bole but left the tree standing. The *cut* category was reserved for completely felled trees and stumps.

Results

Density

The density of *A. crassna* in the two sites was a dramatic contrast from the low density of other *Aquilaria* populations in Southeast Asia (Figure 3). With 7.4 and 15.4 trees per hectare respectively, Mo Singto and Khlong Sai contain comparatively high densities of *Aquilaria*. In contrast, the highest density of *Aquilaria* (≥ 10 cm dbh) in the Center for Tropical Forest Science sites Lambir Hills National Park (Lee et al. 2001), Pasoh Forest Reserve (LaFrankie 1994), and Bukit Timah Nature Reserve (Lum et al. 2000) was 0.9 trees per hectare. In West Kalimantan, Borneo, Paoli et al. (in press) found *A. malaccensis* densities ranging from 0.16- 0.32 trees per hectare (≥ 20 cm dbh) in five forest formations of Gunang Palang Forest Reserve.

While the data from Mo Singto and Khlong Sai indicate that Khao Yai National Park supports both the highest documented density of the *Aquilaria* genus in Southeast Asia, higher density concentrations of *A. crassna* are found within the Park. Near the Khlong Sai study area, a small plot (.12 ha) was delineated around a cluster of 27 trees with a density of 225 stems per ha, demonstrating the species' capacity to form high density stands. Further research is necessary to determine the causes of such clusters.

Dispersion

Morisita's Index of Aggregation determined that the dispersion pattern of *Aquilaria crassna* was aggregated in the two sites (Figure 4). The Mo Singto population of *Aquilaria crassna* (I_d= 2.98, N=714, F= 1.59, a< .001), was more highly aggregated than that of Khlong Sai (I_d= 1.23, N=110, F= 1.17, a=.20). In both sites, the areas of high *Aquilaria crassna* aggregation were moderately closed-canopied forest comprised of two to three strata with a relatively open understory. *Aquilaria crassna* was not found in gaps or areas with dense understories.

Size Class Distribution

The size class distribution for the Mo Singto site reveals discontinuous recruitment and possible long-term population problems due to poor regeneration (Figure 5). While the overall size class distribution loosely follows a reverse J-shaped curve indicative of a healthy, stable self-replacing population, the smaller size classes show possible recruitment difficulties. There is a dramatic drop in stem density in the 50-100cm height class which recovers in the next two categories until zero individuals are found in the 5-10 cm dbh category. *Aquilaria crassna* stems greater than 10 cm dbh exhibit an almost constant decrease in numbers. This size class distribution suggests possible recovery from previous seasons of recruitment difficulties. The smallest size class (<50 cm height) shows about twice as many stems per hectare as the next size class (50-100 cm). Since there has been little baseline research on *Aquilaria crassna*, this size class distribution cannot be compared.

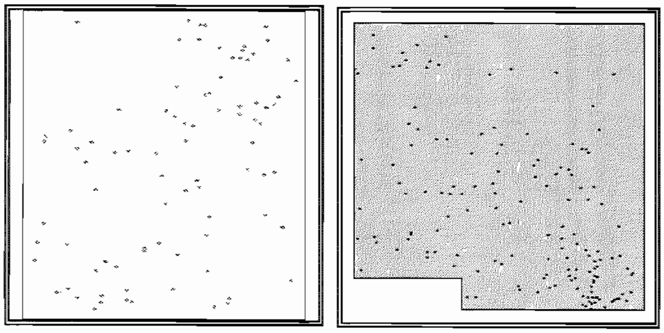
Khlong Sai

The size class distribution of Khlong Sai depicts a more pronounced

Figure 3: Comparison of *Aquilaria* spp. in Southeast Asia

Site	Species	Basal Area/Ha	# Stems	Area (ha)	Stems/ha
Mo Singto Khao Yai National Park Thailand (Mahidol University 2000)	*Aquilaria crassna*	0.27027	215 (>10 cm)	28.56	7.53
Khlong Sai Khao Yai National Park Thailand	*Aquilaria crassna*	0.62	154 (>10 cm)	8.8	17.5
Khlong Sai High Density Plot Khao Yai National Park Thailand	*Aquilaria crassna*	13.6	27	0.12	225
Pasoh Forest Reserve Malaysia (La Frankie 1994)	*Aquilaria malaccensis*	0.0312	80 (>1,<10cm) 45 (> 10 cm)	50	1.6 0.9
Gunang Palang West Kalimantan, Indonesia (Paoli et al. in press)	*Aquilaria malaccensis*		>20 cm	125	0.16-0.32
Bukit Timah Nature Reserve Singapore (Lum et al. 2000)	*Aquilaria malaccensis*	0.0028	5 (>1,<10cm)	2	2.5
Lambir Hills National Park Sarawak, Malaysia (Lee et al. 2001).	*Aquilaria beccariana*	0.0021	284 (>1,<10cm) 1 (>10 cm)	52	5.46 0.019
	Aquilaria malaccensis	0.0199	139 (>1,<10cm) 19 (>10cm)	52	2.67 0.365

Figure 4: ***Aquilaria crassna*** **stem maps in Khao Yai National Park.** In both sites, the spatial distribution of this species is aggregated. *Left:* Khlong Sai Study Site (4.4 hectares). *Right:* Mo Singto Forest Dynamics Plot (28.56 hectares).



reverse J-shaped curve (Figure 6). In the first two size classes, there are relatively high densities of *Aquilaria crassna* followed by a notable drop in density that steadily decreases as size increases. A visual analysis of this size class distribution would suggest that the *Aquilaria crassna* population in Khlong Sai is stable and self-replacing. With the smallest size classes represented in densities two orders of magnitude greater than reproductive trees (approximately >15 cm dbh), recruitment difficulties are not apparent.

Although the shape of the size class distribution does not obviously connote recruitment difficulties, the high level of *mai hom* exploitation of the large-diameter trees in this site may present regeneration difficulties in the future. The population of *A. crassna* needs a sufficient number of healthy mature individuals to promote recruitment. As in Mo Singto, without baseline data and complete knowledge of the species' life history, it is difficult to assess whether the current population of mature adult trees will be able to meet its reproductive needs in light of the current heavy level of poaching. It is imperative that the population of *Aquilaria crassna* be monitored to assess regeneration and triage possible recruitment problems.

Discussion

When compared to other *Aquilaria* populations Southeast Asia, the density of *A. crassna* in Khao Yai National Park is extremely high, indicating the importance of the populations in this study both ecologically and economically. Additionally, it cannot be discerned whether this size class distribution and the apparent regeneration difficulties are the result of *mai hom* extraction. A study of the reproductive success of mature trees would provide a more accurate assessment of regeneration requirements.

Aquilaria crassna colonizes in a highly aggregated manner, favoring forest formations in the understory reinitiation stage of stand development (Oliver and Larson 1996) where this species can succeed in a stratified, partially open-canopy moist forest. In Mo Singto, the population of *Aquilaria crassna* exhibits a highly aggregated dispersion pattern over spatially discontinuous microsites. This high level of aggregation may be attributed to the significant topographical and ecological heterogeneity of the study site, leading to high *Aquilaria crassna* concentrations in areas where the species is most competitive. High aggregation may also be attributed to poor seed dispersal. In Khlong Sai, *Aquilaria crassna* is both less aggregated and found at a higher density than in Mo Singto. These findings may be due to greater site homogeneity, decreased levels of species diversity, and more favorable ecological site conditions.

In the two sites, the data suggest possible regeneration and recruitment difficulties of *Aquilaria crassna*. The size class distribution of Mo Singto indicates recruitment difficulties in the smallest size classes that will detrimentally affect the number of individuals moving into the larger size classes. The high density of individuals in the seedling size class may be a positive indicator of improved regeneration in this study site where *mai hom* extraction has been dramatically curtailed since the establishment of the 27-ha demographic plot. This decrease in *mai hom* extraction will hopefully increase the reproductive vigor of mature trees, which can then divert water and nutrient resources from repair to reproduction. Thus, the relatively high density of individuals in the seedling size class and the increased reproductive potential of mature trees in Mo Singto are positive steps toward returning this population to a healthy trajectory.

The size class distribution of Khlong Sai follows an inverse J-shaped curve indicative of a stable self-maintaining population. However, because intensive *mai hom* exploitation in Khlong Sai has only occurred within the last few years, there may be a time lag before recruitment difficulties are fully detectable. This population must be monitored to assess regeneration and current and long-term population trends.

These analyses of size class distributions should be augmented by phenological studies. During this study, fruit sampling

Figure 5: Size class distribution of *Aquilaria crassna* in Khlong Sai

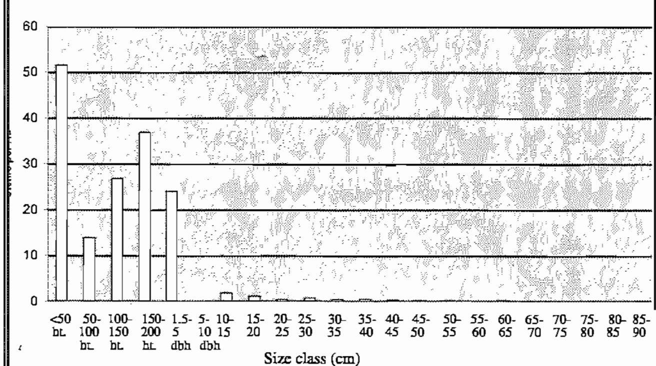
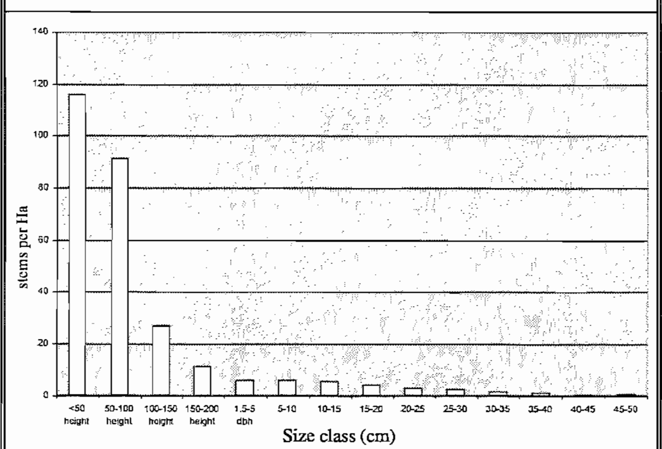


Figure 6. Size class distribution of *Aquilaria crassna* in Mo Singto



was conducted to calculate the species' phenological conversion efficiency (the ratio of fruit production to stem recruitment). These findings will be used to estimate the number of mature trees necessary to maintain the population in each of the two study sites. Further analysis will explore the effects of varying levels of *mai hom* exploitation on fruit production and regeneration.

Future research goals include a better understanding of the natural history of *Aquilaria crassna* as well as the potential long-term effects of *mai hom* exploitation in the park. This research will supplement *Aquilaria* research in other Asian forests and may be used to create management plans to meet socio-economic and ecological objectives. Possible applications include sustainable *mai hom* extraction, *Aquilaria crassna* plantations, initiating community-based development programs, and improved *Aquilaria* management in protected areas.

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References

Brockelman, W.Y. and P. Charoenchai. 1999. Khao Yai Forest Dynamics Plot Established in Gibbon Study Site. *Inside CTFS.* Summer 1999. Center for Tropical Forest Science. Smithsonian Tropical Research Institute, Washington D.C.

Burkhill, I. H. 1935. A Dictionary of the Economic Products of the Malay Peninsula. The Governments of the Straits Settlements and Federated Malay States by the Crown agents for the colonies, London.

Chakrabarty, K., A. Kumar and V. Menon, 1994. *Trade in Agarwood.* WWF-India, New Delhi.

Condit, R. 1998. *Tropical Forest Census Plots.* Springer-Verlag, New York.

De Beer, J. and M. McDermott, 1989. *The economic value of non-timber forest products in Southeast Asia with emphasis on Indonesia, Malaysia and Thailand.* IUCN, Amsterdam.

Jalaluddin, M. 1977. A useful pathological condition of wood. *Economic Botany.* 31:222-224.

Klinhom, U. 1997. *Cultural Forest Conservation in Northeastern Thailand: A Model Study in Community Based Sustainable Resource Management.* Office of Environmental Policy and Planning, Bangkok, Thailand. Unpublished.

LaFrankie, J V. 1994. Population dynamics of some tropical trees that yield non-timber forest products. *Economic Botany* 48: 301-309.

Lee, H.S., J.V. LaFrankie, S. Tan, T. Yamakura, A. Itoh, and P.S. Ashton. 2001. Demographic tree data from the 52-ha Lambir Forest Dynamics Plot. CTFS Forest Dynamics Plot Data Series. CD-Rom. Sarawak, Malaysia.

Lum, S.K., S.K. Lee, J.V. LaFrankie 2000. Demographic tree data from the 2-ha Bukit Timah Forest Dynamics Plot. CTFS Forest Dynamics Plot Data Series. CD-Rom. Singapore.

Mahidol University 2000. Database for Mo Singto Forest Dynamics Plot, Khao Yai National Park, Thailand. Center for Conservation Biology, ISTRD, Salaya, Thailand

Mittelman, A.J., C.K. Lai, N. Byron, G. Michon, and E. Katz, 1997. *Non-Wood Forest Products Outlook Study for Asia and the Pacific: Towards 2010.* Asia-Pacific Forestry Sector Outlook Study Working Paper No. APFSOS/WP/28. FAO, Rome.

Nan, C. and W.Y. Brockelman, 1998. A Flexible Method for Forest Plot Data Collection and the TreeXY Software. Forest Diversity and Dynamism: Results for the Global Network of Large-Scale Demographic Plots. Center for Tropical Forest Science Conference 1998, Washington, DC.

Nepstad, D.C. and S. Schwartzman (Eds.). 1992. *Non-timber products from tropical forests: evaluation of a conservation and development strategy.* New York Botanical Garden, Bronx, New York.

Northeast Thailand Upland Social Forestry Project. 1987. *Human-forest interactions in northeast Thailand.* Bangkok: Northeast Thailand Upland Social Forestry Project.

Oliver, C.D. and B.C. Larson. 1996. Forest Stand Dynamics. Wiley. New York.

Oyen, L.P.A. and N. X. Dung (Eds.) 1999. Plant Resources of South-East Asia No. 19, Essential-oil Plants. PROSEA Foundation. Bogor, Indonesia.

Paoli, G.D., M. Leighton, D.R. Peart, and I. Samsoedin, in press. Economic Ecology of Gaharu (*Aquilaria malaccensis*) in Gunung Palung National Park: Valuation of Extraction and Ecology of the Residual Population. *Conservation Biology.*

Peters, C. M. 1994. *Sustainable Harvest of Non-timber Plant Resources in Tropical Moist Forest: An Ecological Primer.* Biodiversity Support Program. Washington, D. C.

Plotkin, M. J. and L. M. Famolare (Eds.). 1992. Sustainable Harvest and Marketing of Rain Forest Products. Washington, D.C. Island Press.

Royal Forest Department. 1985. *Khao Yai National Park Management Plan 1985-1989.* National Park Division, Ministry of Agriculture and Cooperatives.

Royal Forest Department, 1990. *Nomination of Khao Yai National Park to be a UNESCO World Heritage Site.* February 15, 1990. National Park Division. Royal Forest Department. Thailand.

Social Forestry Research Project. 1991. *Social forestry project in northeast Thailand: an experience from a multi-agency collaborative project to establish participatory forest manual.* Khon Kaen, Thailand: The Social Forestry Research Project.

Smitinand, T. 1968. Vegetation of Khao Yai National Park. *Natural History Bulletin of the Siam Society.* 22:289-303.

Allometric regression for improved estimation of carbon sequestration of two neotropical tree species

Christopher Losi, MF 2001
and Juan Morales

Introduction

Tropical tree plantations have long been suggested as an effective means of reducing the atmospheric pool of CO_2(Dyson 1977). As trees grow, they sequester carbon in their tissues, so that as the amount of tree biomass increases, the addition of CO_2 to the atmosphere by fossil fuel use is mitigated. Through the Kyoto Protocol's Clean Development Mechanism (CDM), the ability of plantations to sequester carbon has received renewed interest, since carbon sequestration projects in developing nations could receive investments from companies and governments wishing to offset their emissions of greenhouse gases (Fearnside 1999).

The rate of carbon sequestration in live tree biomass is computed by finding the difference between the carbon content of a plantation or forest at two different times. As dry biomass is generally estimated to contain about 50% carbon by weight (Brown 1997; Montagnini and Porras 1998) estimates of forest biomass are often used as a surrogate measure. While the simplest way to estimate carbon is just to use a published value of biomass for a similar plantation or forest, more accurate estimates require measuring the trees and using either converted volume estimates or biomass regression equations. The regression equations (also called allometric regressions) are mathematical functions that describe oven-dry biomass per tree as a function of a single or a combination of tree dimensions (Brown 1997).

Allometric regressions can be extremely general, even pan-tropical (Crow 1978) or extremely specific, such as those appropriate for a particular time of year for a single species (Verwijst and Telenius 1999). In general, it is believed that a biomass (or carbon) allometric regression is applicable to trees of the same species for which it was developed, regardless of spacing or age (Fownes and Harrington 1992; but see Verwijst and Telenius 1999). However, the models should only be applied to trees of similar size to those used to develop the model.

In this paper, I present allometric regressions relating aboveground carbon content to DBH in 7 year-old *Anacardium excelsum* and *Dipteryx panamensis* growing in experimental plantations on abandoned farmland in Panama. In addition, I present estimates of total aboveground carbon present in *A. excelsum* and *D. panamensis* in the experimental plantation where I developed my models. Finally, I compare the predictive ability of these models to those developed by Nelson et al. (1999), Montagnini and Porras (1998) and Shepherd (1998) for other tropical species.

Methods

Site Description

Research was conducted on 42 plantation plots set up by Juan Morales and Richard Condit of the Center for Tropical Forest Science at the Smithsonian Tropical Research Institute (CTFS- STRI). Trees of five species: *A. excelsum* and *D. panamensis* as well as *Enterolobium cyclocarpum*, *Hura crepitans*, and *Swietenia macrophylla* were planted in September 1993 in mixed species plots near the villages of Los Hules, Las Pavas, and Cerro Cama (Figure 1).

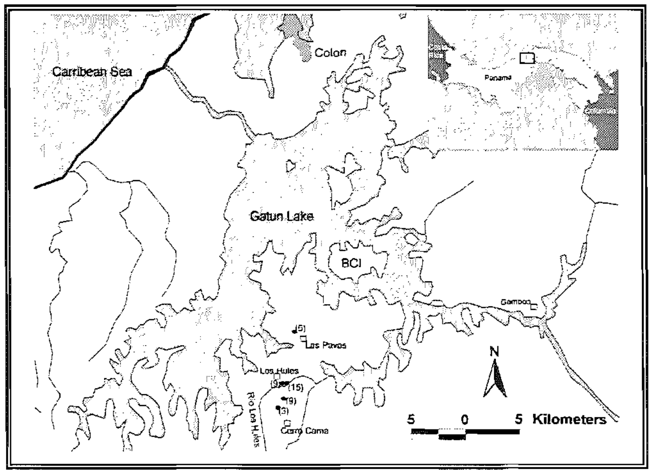


Figure 1—Map of the study site. Plantation plots were set up on private farms in and around the villages of Cerro Cama, Los Hules, and Las Pavas (squares). Each dot on the map represents a different landowner who agreed to have plots established on his or her land. The value in parentheses is the number of plots on that property. Life zone and climate data are from observations made on Barro Colorado Island (BCI).

This area is just west of Gatun Lake, the artificial lake through which ships pass on their journey through the Panama Canal. Located in Gatun Lake less than 20 km from the study site, Barro Colorado Island (BCI) belongs to the "tropical moist forest" life zone (Croat 1978), has an annual temperature range from 21° to 31° and an average annual rainfall of 2647 mm. Average monthly rainfall on BCI varies from 50mm/month during the dry season (January to April) to 300mm/month during the rainy season (Patton 1994). For the purposes of this paper, it is assumed that the climatic conditions at the study site are similar to those on BCI.

Trees were planted in 10m × 10m plots at a planting distance of 2m × 2m. Each plot had all five species planted in a semi-randomized design such that each row usually had one individual of each species. Border rows of the same spacing were planted around each plot to reduce edge effects. All of the 42 plots had been established on private lands that had become unsuitable for farming. The lands belonged to five different farmers, with three to fifteen plots located on each property (Figure 1). Based on previous research (Losi 1996) which considered growth form and absence of disease, it was decided that *D. panamensis* and *A. excelsum* were the most promising candidates out of the five species for plantation-grown timber.

Tree Selection

DBH and carbon content were measured on 14 trees of each species across a broad range of tree sizes. In June and July 2000, DBH was measured for all *D. panamensis* and *A. excelsum* individuals in plots as well as those in internal border rows (border rows surrounded on both sides by a plot). The trees were separated into size classes and

Figure 2. Fresh biomass was measured on a hanging digital scale

a simple random sample of five trees chosen for carbon measurement. Nine trees were then selected from the upper two thirds of the diameter range using a systematic sampling strategy, so that tree diameters were spread out across the range of diameters for that species. The largest tree of each species was not harvested on any farm out of deference to the wishes of the property owners. Farmers were paid for each tree extracted.

Harvesting took place over three weeks in July and August. DBH was measured immediately before felling since some growth had usually occurred since the initial measure. Height was measured on the ground after felling. The tree was then separated into different tissue types: bole, branches, dead wood, twigs, and leaves, and each tissue type was weighed on a portable hanging scale (Figure 2). Twigs were defined as the current season's growth; generally they were green and had leaves. Since the trunk was not perfectly vertical, the bole was identified as all living wood that led up to the highest point on the tree. The bole was cut into 2m sections, which were then weighed. Branches were defined as all living wood not classified as twigs or bole.

Sample Processing

After the entire tree had been weighed in pieces, samples were taken from each tissue type. Ten leaves were chosen at random from each tree. A 5cm slice of wood was taken from the bottom of each 2m bole section. Ten twig pieces were selected by first selecting ten twigs at random, then cutting them into pieces 5cm long and selecting ten pieces at random from this sample. Dead wood was sampled in the same way. Branches were sampled systematically from largest to smallest: straight branch segments were sorted by diameter, placed in a line, and a 5cm long piece was cut at equidistant points along that line such that approximately ten pieces were chosen. This sampling strategy ensured that a wide range of branch sizes was sampled.

Individual samples for each tissue type were pooled, sealed in plastic bags, transported to the STRI laboratory in Panama City and weighed there. Samples were dried on open ovens in a drying room at approximately 80°C for about a week and weighed again. All samples were then shipped to New Haven, CT where half of the woody samples were dried at 105° C and the other half of the woody samples plus all of the leaves were allowed to acclimate to ambient temperature/humidity and weighed again. The latter samples were then ground to pass through a 0.5mm screen (1.0 mm screen for leaves), and analyzed for percent carbon on a LECO® CHN-600 analyzer.

Percent carbon values obtained in this manner were dependent on the moisture content of the wood at the time of analysis. These values were corrected for the water gain which occurred after removal from the 80° oven. The result was a ratio which expressed carbon as a percentage of the wood dried for one week in Panama. These ratios could then be applied to wood samples which were not analyzed for carbon.

Wood density was measured on the 2m bole disk for the nine *A. excelsum* individuals dried at 105°C. Density was not measured for *D. panamensis* since pieces tended to lose bark and develop cracks. Density is generally computed as dry weight / fresh volume in the neotropics (Chudnoff 1984; Brown 1997); however, volume measurements in this paper were made after the wood had already been dried. Volume was determined by measuring diameter and thickness of the disk at different positions.

Model Development

After computing the average carbon percentage for each tissue type, I was able to estimate the carbon content of samples that were not analyzed. As a sample of leaves from each tree was analyzed for carbon, a surrogate measure for this tissue type was not needed. The carbon content of each sample was then used to estimate the carbon present in each tree. Allometric regressions were created by relating these carbon estimates to the tree's DBH and height. Following Nelson et al. (1999), the following indicators of goodness of fit are reported for each model.

- -- *r^2 of the simple regression*
- -- *Standard error*: reported for the intercept and for partial regression coefficients of the independent variables
- -- *Significance of t-value*: reported for each independent variable
- -- *Average unsigned deviation*: an indicator of accuracy in the estimation of individual tree biomass values.

For each tree used in a regression, the average deviation between predicted dry weight and observed dry weight was expressed as a percentage of observed dry weight. Finally, the allometric regressions were used to estimate the amount of carbon present in 7 year-old *D. panamensis* and *A. excelsum.*

Table 1. General data on size and specific density of wood for *A.excelsum* and *D. panamensis* in the plots studied

Parameter	Units	*A. excelsum*	*D. panamensis*
Survival	%	73.3%	74.8%
Smallest DBH	cm	1.5	0†
Largest DBH	cm	27.7	20.8
Mean DBH	cm	9.4	7.5
Median DBH	cm	9.1	7.9
Specific density of wood (Chudnoff, 1984)	g/cm^3	0.410	0.855 (range 0.8 - 0.91)
Specific density (measured)	g/cm^3	0.353	NA
Specific density("best guess")	g/cm^3	0.353	0.800

† One individual was still less than 1.3 meters tall. four others had been cut and were sprouting from the stump

Table 2. Regression models for estimation of above-ground biomass of 14 trees each of *Anacardium exelsum* and *Dipteryx panamensis*. Trees ranged in size from 2.4 to 18.6 in *A. excelsum* and 1.8 to 11.2 in *D. panamensis*

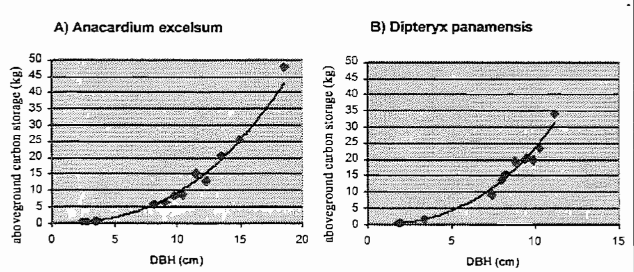
Regression Model	Species	Symbol	Value	Goodness of Fit Indicators: Standard error	r^2	Average unsigned deviation	Significance level of t-value
$\ln(c) = c + \alpha \ln(DBH)$	*A. excelsum*	c	-3.5289	.1045	0.995	7.0%	< 0.0001
		α	2.4894	.0501			< 0.0001
$\ln(c) = c + \alpha \ln(DBH) + \beta \ln(H)$		c	-3.7044	.2431	0.995	7.2%	< 0.0001
		α	2.2623	.2874			< 0.0001
		β	0.3227	.4021			NS (0.4)
$\ln(c) = c + \alpha \ln(DBH)$	*D. panamensis*	c	-2.6263	0.0719	0.997	5.3%	< 0.0001
		α	2.5072	0.0391			< 0.0001
$\ln(c) = c + \alpha \ln(DBH) + \beta \ln(H)$		c	-2.8180	0.1138	0.998	4.0%	< 0.0001
		α	2.1838	0.1626			< 0.0001
		β	0.4020	0.1975			< 0.1

study have lower wood density than the trees that were measured by Chudnoff's (1984) sources, "best guess" density values are given in table 1. *D. panamensis* has been assigned a value of 0.8 g/cm³ (the lower limit of the published range) and *A. excelsum* has been assigned a value of 0.353 g/cm³.

Developing the models

Aboveground carbon content of each tree was plotted against DBH for both species in Figure 3. Best fits were attained using an exponential relationship. However, in order to facilitate comparison to linear models in other papers (Nelson et al. 1999), both DBH and carbon were ln-transformed, and a linear regression was made. The four indicators of goodness of fit are shown in table 2 for all regressions that were developed in this paper. Two of the regressions incorporate height as a second independent variable, while the other regressions has DBH as the only independent variable. However, the coefficient for height is significant at only the 10% level for *D. panamensis* and not at all significant for *A. excelsum* (Table 2).

Figure 3. Scatter plots for *Anacardium excelsum* and *Dipteryx panamensis* indicate a straong nonlinear relationship between aboveground carbon storage and DBH, as shown by the following regression: a) C = 0.0293(DBH)2.4894, r^2 = 0.9952 b) C = 0.0723(DBH)2.5072, r^2 = 0.9971 where C is total aboveground carbon storage and DBH is diameter at breast height.



Results

General Data

Out of an original 210 individuals of each species in the 42 plots, 154 *A. excelsum* and 157 *D. panamensis* were living when they were measured in June 2000. Table 1 shows DBH and wood density statistics for the two species. *A. excelsum* was slightly larger than *D. panamensis* on average (9.4 cm DBH vs. 7.5 cm). While these two species were generally the tallest in the plots, the canopy was made up mostly of another species, *Hura crepitans*. Large individuals of *D. panamensis* and *A. excelsum* grew above the canopy but had not yet grown wide enough for the crowns to cast side shade, while smaller individuals of these species grew beneath the *Hura crepitans* in nearly full shade.

The average wood density of *A. excelsum* was 0.353 g/cm³. Not a single piece from this species had a measured density greater than or equal to the published value of 0.41 g/cm³ (Chudnoff 1984). There was no relationship between wood density and DBH. Furthermore, had density been measured following the standard procedure, the wood density for these trees would almost certainly have been even lower. Because of the possibility that the trees in this

Carbon Estimates and cross-validation with published mixed-species regressions

For the 7-year old trees on these plantation plots, the average 9.4 cm DBH *A. excelsum* should have 7.8 kg of aboveground carbon and the average 5.7 cm DBH *D. panamensis* should have 11.3 kg of aboveground carbon. Carbon estimates for the entire population of trees were made by applying the first and third equations from table 2 to the DBH measurements taken in June 2000 for all trees in the 42 plots. The totals are 1756.8 kg for *A. excelsum*, and 2301.0 kg for *D. panamensis* on the 42 plots. As the study area covered a total of 0.42 ha (42 10×10 m plots) with 0.084 ha devoted to each species (0.42 ha / 5 species) the carbon content of these trees can be expressed as 20.9 Mg/ha (Mg = 1000 kg) for *A. excelsum* and 27.3 Mg/ha for *D. panamensis*.

This value for *D. panamensis* can be compared with biomass estimates made in Costa Rica. In pure plantations of *D. panamensis* at the La Selva Biological Station, Montagnini and Porras (1998) estimated a carbon content of 14.55 Mg/ha for 3 year old trees and Shepherd (1998) estimated a carbon content of 19.6 Mg/ha for 5 year old trees. Both of these authors first estimated dry biomass and then multiplied by 0.5.

Unfortunately, neither of these papers gives the allometric regressions that they used to estimate biomass, so it is not possible to compare models specific to *D. panamensis* between the two sites. In figure 4, the equations created in this paper are compared to mixed-species equations developed recently by other researchers for the Amazon Basin (Nelson et al. 1999). Scatter plots of DBH vs. signed percent error in the estimate of individual tree biomass values are shown in Fig 3 for three published regressions developed by Nelson et al. (1999). For each graph, the points show the degree to which the equation over or underestimates the biomass. The equation for parts C & D of figure 4 uses the average wood density of the species (denoted specific density or SD) as an independent variable. The

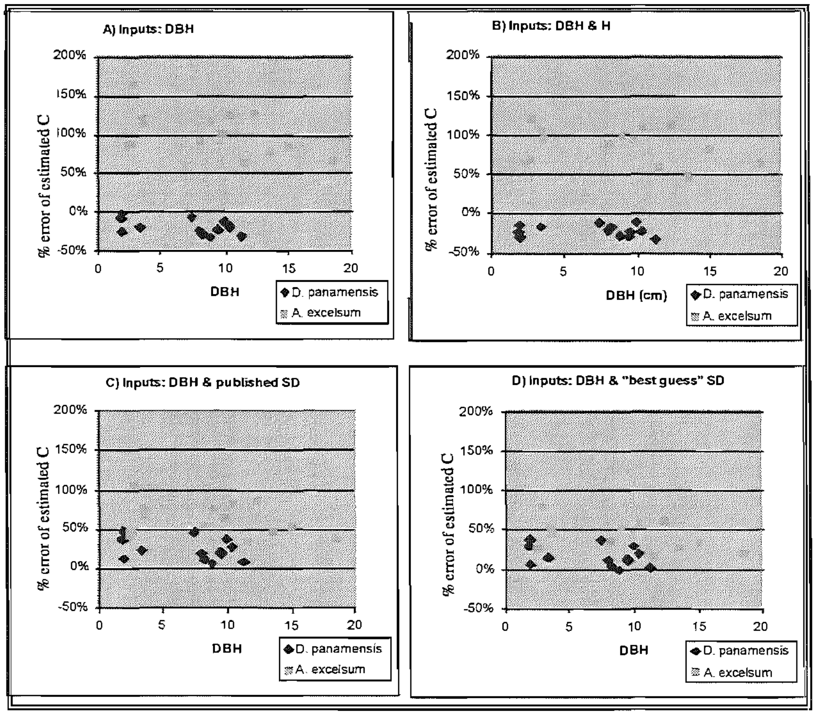


Figure 4. Errors of three published mixed-species regression equations (Nelson et al., 1999) when used to predict total aboveground carbon for each tree in this study. The distance of each point above or below the 0% line indicates the degree to which the model over or underestimates carbon for that tree. Plots C and D use the same model but different values are used for specific density (SD). Plot C uses SD values from Chudnoff (1984), and plot D uses "best guess" as described in the text. Equations are as follows:

a) $C = \exp(2.4128\ln(DBH) - 1.9968)/2$

b) $C = \exp(2.1400\ln(DBH) + 0.4644¥\ln(H) - 2.5202)/2$

c & d) $C = \exp(2.4449\ln(DBH) + 0.9028\ln(SD) - 1.4702)/2$

where C is total aboveground carbon, DBH is diameter at breast height, H is height, and SD is specific density of the wood.

first graph uses published (Chudnoff 1984) values for biomass and the second uses "best guess" values as shown in table 1. Finally, the published regressions were applied to all of the trees in the 42 plots and compared to the estimates given in this paper (Table 3). The regression involving DBH and height was not applied to the plantation plots since height was not measured on each tree. The estimates of dry biomass calculated using the published models were multiplied by 0.5 in order to compare with the carbon estimates made in this paper.

Discussion

Carbon accumulation for *D. panamensis* appears to be similar to rates reported in the La Selva research station, Costa Rica. No data could be located for *Anacardium excelsum*. It appears clear that by far the most accurate models are those developed specifically for the species of interest. Nevertheless, it may be somewhat helpful to know that models developed for totally different species in the Brazilian Amazon still provided estimates of carbon accumulation accurate within a factor of two. If no species-specific models are available, an accurate value for wood density seems to be extremely useful; the data here suggest that it is much more useful than tree height. A good estimate of wood density, however, may require more than a literature search. Juvenile wood (generally the inner 12 rings, or so) is less dense than mature wood (Desch and Dinwoodie 1996). Since Chudnoff (1984) was writing for an audience concerned about timber properties, it is almost certain that the wood samples came from larger trees with only a small fraction of juvenile wood. Also, the samples measured in this paper and in Nelson et al. (1999) included bark, which is less dense than wood, while a timber handbook would have used measurements taken from bark-free wood.

Density is still probably only part of the story. Differences in taper, crown form and height:diameter ratio all play a role. Of course, there comes a point at which collecting species-specific information is no easier than developing a new model from scratch. Also, while adding multiple species certainly adds complexity, it may also reduce the effect of species that deviate greatly from the model. For example, while the simplest mixed-species model examined here (Nelson et al. 1999, DBH only) overestimates *A. excelsum* carbon content by 90% and underestimates *D. panamensis* carbon by 24%, the sum of both species when grown together in plantation is overestimated by only 25%.

Table 3. Estimates of aboveground carbon using generic, mixed-species equations, and the degree to which these over or underestimate the "true" carbon values.

Inputs	*A. excelsum* Carbon (Mg/ha)	error of estimate	*D. panamensis* Carbon (Mg/ha)	error of estimate
This paper				
DBH	20.9	--	27.3	--
Nelson et al., 1999				
DBH	39.7	+90.0%	20.7	-24.2%
DBH, SD (Chudnoff)	32.6	+56.0%	32.8	+20.1%
DBH, SD ("Best Guess")	28.5	+36.4%	30.9	+13.2%

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References

Brown, S. (1997). Estimating biomass and biomass change of tropical forests: a primer. Rome: Food and Agriculture Organization of the United Nations. FAO Forestry Paper 134. 55p.

Chudnoff, M. (1984). *Tropical timbers of the world.* USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin, Agriculture Handbook Number 607.

Croat, T.R. (1978). *Flora of Barro Colorado Island.* Stanford University Press, Stanford, California.

Crow, T.R. (1978). Common regressions to estimate tree biomass in tropical stands. *Forest Science,* 24(1):110-114.

Desch H.E. and J.M. Dinwoodie. (1996). Timber: Structure, properties, conversion, and use. 7th Edition. Food Products Press (An imprint of the Haworth Press) New York.

Dyson, F.J. (1977). Can we control the carbon dioxide in the atmosphere? *Energy* (Oxford) 2:287-291.

Fearnside, P.M. (1999). Forests and global warming mitigation in Brazil: opportunities in the Brazilian forest sector for responses to global warming under the "clean development mechanism." *Biomass and Bioenergy* 16:171-189.

Fownes, J.H. and R.A. Harrington. (1992). Allometry of woody biomass and leaf area in five tropical multipurpose trees. *Journal of Tropical Forest Science.* 4(4):317-330.

Losi, C.J. (1996). Carbon sequestration rates of five neotropical tree species and their feasibility for establishment in commercial plantations. Unpublished undergraduate thesis, Princeton University.

Montagnini, F. and C. Porras. (1998). Evaluating the role of plantations as carbon sinks: an example of an integrative approach from the humid tropics. *Environmental Managment* 22(3):459-470.

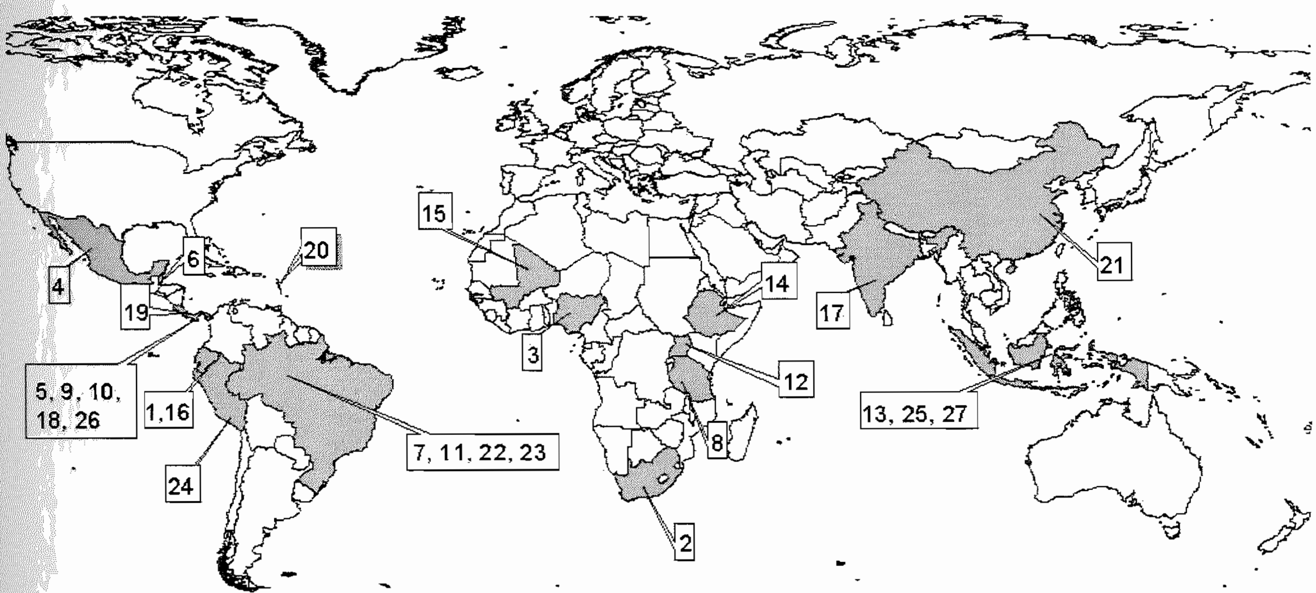
Nelson, B.W., R. Mesquita, J.L.G Periera, S.G. Aquino de Souza, G.T. Batista, L.B. Couto. (1999). Allometric regressions for improved estimate of secondary forest biomass in the central Amazon. *Forest Ecology and Management* 117:149-167.

Patton, S. (1995). 1994 Meteorological and Hydrological Summary for Barro Colorado Island. (unpublished data). Smithsonian Tropical Research Institute, Balboa, Panama.

Shepherd D. (1998). Mixed-species tree plantations in the humid tropics: an alternative for carbon sequestration. *TRI News* 17:14-18.

Verwijst T. and B. Telenius. (1999). Biomass estimation procedures in short rotation forestry. *Forest Ecology and Managment.* 121:137-146.

2001 Tropical Resources Institute Research Sites



Masters Student Internships for 2001

1. **Maria Paola Amador:** Ecuador
2. **Sarah Canham:** South Africa
3. **James Coleman:** Nigeria
4. **Citlali Cortes:** Mexico
5. **Maria Ana de Rijk:** Panama
6. **Erika Diamond:** Belize
7. **Roberto Frau:** Brazil
8. **Cassie Hays:** Tanzania
9. **David Howlett:** Panama
10. **Libby Jones:** Panama
11. **Eirivelthon Lima:** Brazil
12. **Carrie Magee:** Uganda
13. **Nissa Mardiah:** Indonesia
14. **Yemeserach Megenasa:** Ethiopia
15. **Jeff Morton:** Mali
16. **Sally Nunnally:** Ecuador
17. **Nalini Rao:** India
18. **Rachel Roth:** Panama
19. **Marc Stern:** Costa Rica, Ecuador
20. **KimThurlow:** Dominica
21. **Guoqian Wang:** China

Doctoral Student Internships For 2001

22. **Marina T. Campos:** Brazil
23. **Anna Fanzeres:** Brazil
24. **Cesar Flores:** Peru
25. **Laura Meitzner:** Indonesia
26. **Heather Peckham:** Panama
27. **Steve Rhee:** Indonesia

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Volume 20

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