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Conservation or Conversion of Mangroves in Fiji

Padma Narsey Lal

East-West Center

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An Ecological Economic Analysis

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by

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FOREWORD

The study of mangrove ecosystems has proved to be particularly interesting. As linked terrestrial-aquatic systems, they illustrate the interrelated nature of many coastal resource systems. Since the mangroves are influenced by land use decisions taken in the watershed areas above them, they are affected by land use decisions made both in the mangrove and at some distance away. Similarly, they serve various important ecological and biological functions in the aquatic part of their life zone. The effects of the various decisions made about management of mangroves and the watersheds on which they in part depend have important economic implications for coastal societies.

This Occasional Paper, based on Dr. Lal's Ph.D. dissertation at the University of Hawaii, is an excellent illustration of applying economic analysis to a complex natural resource ecosystem. Dr. Lal examines mangrove conversion and use in Fiji and analyzes ecological and economic dimensions of mangrove management actions. She demonstrates how traditional economic analysis misses many of the important economic benefits associated with healthy mangrove ecosystems and how a broader linked ecological-economic analysis captures many more of the important factors necessary to make informed decisions about mangrove conservation or conversion.

Whether mangroves are maintained to provide the wide range of benefits that we are increasingly becoming aware of, or whether they are converted to other agricultural or infrastructure uses, this analysis will be extremely important in ensuring that correct decisions are made. Dr. Lal's detailed discussion of the factors involved and her efforts to place monetary values on many of these variables serve as a valuable guide for future work in this area.

John A. Dixon
Research Associate

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Last but not least, I thank my family for their support and understanding. My children--Niraj (6) and Yogi (13)--put up with many inconveniences, and Brij contributed more than his editorial skills to this study. Without his love and understanding--and arguments--this study would have taken longer to complete. No words can adequately express my affection and gratitude to my family.

ABSTRACT

It is generally agreed that developments involving complex ecosystems can be undertaken neither purely within the traditional neoclassical economics framework nor entirely within an ecological one. The basic questions in managing an ecologically dynamic and complex ecosystem, such as mangroves, are, "Under what conditions should it be maintained and managed for its in situ uses, such as the dependent fisheries and forestry resources?" and "When should it be reclaimed for alternative purposes?" In addition, how should one evaluate such a complex ecosystem in order to facilitate ecologically as well as economically rational decisions? These are the central questions I will address using an expanded benefit-cost (BC) analysis framework with Fiji mangroves as a case study.

The model, which uses an ecosystem approach, includes the value of the growing and harvested resource and the effects of ecological constraints on development benefits and costs.

In the empirical application of the model to the two ongoing projects involving rice and sugarcane/shrimp farming on reclaimed mangrove land, the effects of the ecological constraints of the mangrove ecosystem are incorporated explicitly into the estimation of the net development benefits. Different evaluation techniques, both market and nonmarket ones, are used for estimating the in situ net benefits of the mangrove ecosystem and those of the alternative development projects, and their applicability is discussed.

This study shows that unless the ecological constraints of an ecosystem are incorporated into a BC framework, the society loses a naturally viable ecosystem without receiving positive returns from its alternative uses. A "with and without" analysis, using a 5 percent social discount rate and a 50-year planning horizon, gave a negative net present value (NPV) of the development project on the reclaimed mangrove soils.

The NPV estimates were still negative under the assumption of accelerated desalination process and the use of higher social discount rates and longer planning horizons. At 1 to zero percent social discount rate and a 100-year planning horizon, with no further capital investment, the irrigated rice project gave positive NPV estimates; however, sugarcane/shrimp farming still gave negative returns. Many reasons, besides the high initial capital costs, contributed to the nonviability of the agricultural projects on reclaimed mangrove lands. The inherent ecological characteristics of the tidal mangrove soils--acid sulphate soils with inherent toxic concentration of aluminum and iron and low phosphate retention--are the main causes of high farming costs and low yields. Together with the special farming practices required for the reclaimed mangrove soils and regular costs of bund wall maintenance, they contributed toward the negative net returns for both projects.

The study, which adopts an integrated and multidisciplinary approach in project evaluation, has wide applications beyond mangrove conservation in Fiji. A need for a holistic approach that incorporates the interactions of the ecological, economic, and institutional factors and processes in project evaluations is emphasized, as it is the totality of these that determines the outcome of any activity within an ecosystem. In addition, considering the number of uncertainties in situations involving complex ecosystems such as mangroves, an alternative framework for natural resource allocation and management is suggested. In such a framework, extended BC analysis still plays an important role in resource allocation but at a second-tier level.

SECTION 1

INTRODUCTION

Rational use of natural resources relies on a holistic approach in examining the interactions among economic, ecological, and institutional systems, as it is the totality of these that determines the outcome of any activity within an ecosystem. This is particularly critical in ecologically complex natural systems, such as mangroves, which encompass both land-based as well as aquatic subsystems, with the natural movement of water providing the essential linkage between the two. This paper, a revised and considerably condensed version of my dissertation (1989a), demonstrates the importance of adopting an integrated approach in project evaluations by using an extended benefit-cost (BC) analysis framework.

THEORETICAL ECOLOGICAL ECONOMIC CONDITION

Economic theory stipulates that scarce resources should be allocated according to their highest valued use alternative. One of the approaches that can be used to make this choice is BC analysis (Mishan 1976). BC analysis allows a systematic method of identifying and measuring the economic benefit and cost stream of a project over time, upon which a decision to develop or conserve a resource can be made (Hufschmidt et al. 1983). An implicit assumption in the BC analysis is that society will be economically efficient in its use of resources when all costs and benefits are included to maximize the social net benefits.

Final revisions were made while I was a Visiting Fellow at the Center for Resource and Environmental Studies, Australian National University.

A society values a mangrove ecosystem for the extractable resources it supports, for nonconsumptive services it provides, as well as the ecological value of the system. Mangroves support diverse communities of micro and macro terrestrial and aquatic flora and fauna (e.g., Saenger et al. 1977; UNDP/UNESCO 1987). Some of the plant and animal species are of direct and indirect economic and social value to human societies throughout the world (Saenger et al. 1983; Hamilton and Snedaker 1984). Mangrove ecosystems also provide a variety of nonconsumptive services from recreational and aesthetic net benefits, which are derived from their unusual flora and fauna populations, to protection from soil erosion, flood mitigation, filtering of nutrients, and protection of interior lands from saline intrusion (Saenger et al. 1983).

Mangroves are under constant development pressure because they are found in coastal and estuarine areas, which usually are also centers of human settlement. These development activities include the infill of swamp land for residential and industrial uses, construction of seawalls and the drainage of waterlogged saline land for agriculture or aquaculture, and the use of mangrove soils for secondary treatment of sewerage.

The basic questions, then, are: Under what conditions should a natural system, such as mangroves, be maintained and managed for its <u>in situ</u> uses of forestry and fisheries products and other environmental services? When should it be reclaimed to "create" land for alternative purposes? How should one evaluate such a complex ecosystem to facilitate ecologically and economically rational decisions in the absence of a market?

Answers to these questions require an examination of the functional interrelationships between "natural processes and components" and "human needs and activities" (de Groot 1987). That is, it needs a framework within which the goods and services provided by the natural environment and ecological benefits can be included and evaluated along with the more traditional benefits of development. The need for such a balanced approach,

which is broad-based and ecologically oriented, cannot be overemphasized in the context of the mangrove ecosystem.

The problems associated with project evaluations have resulted from the complex nature of the dynamic ecosystem and from the manner in which the BC model has been applied by the relevant institutions and the evaluation techniques adopted. Generally, project boundaries are defined by sectoral use or the physical land site and not by the ecological processes and characteristics of the ecosystem. Thus, this definition completely ignores the fact that wetland ecosystem transcends the traditional land and water boundaries, where any activity in the terrestrial subsystems influences--and is influenced by--the ecological and economic processes within the entire ecosystem.

The ecological importance of the mangroves for sustaining dependent resources are generally recognized, and net ecological and economic/financial benefits of individual activity are analyzed in isolation (e.g., Christensen 1982; Bandopadhyay 1985). But, in the use of BC analysis of development projects on coastal wetlands, often only land-based benefits and costs, and that too of only commercial utilization, and of development projects are included, neglecting in situ benefits of the ecosystem that are spatially removed. For example, the importance of mangroves for sustaining coastal fisheries is acknowledged, but the economic value of the "off-site" fisheries benefits is not included in project evaluation (e.g., Ernest 1983; ADAB 1985).

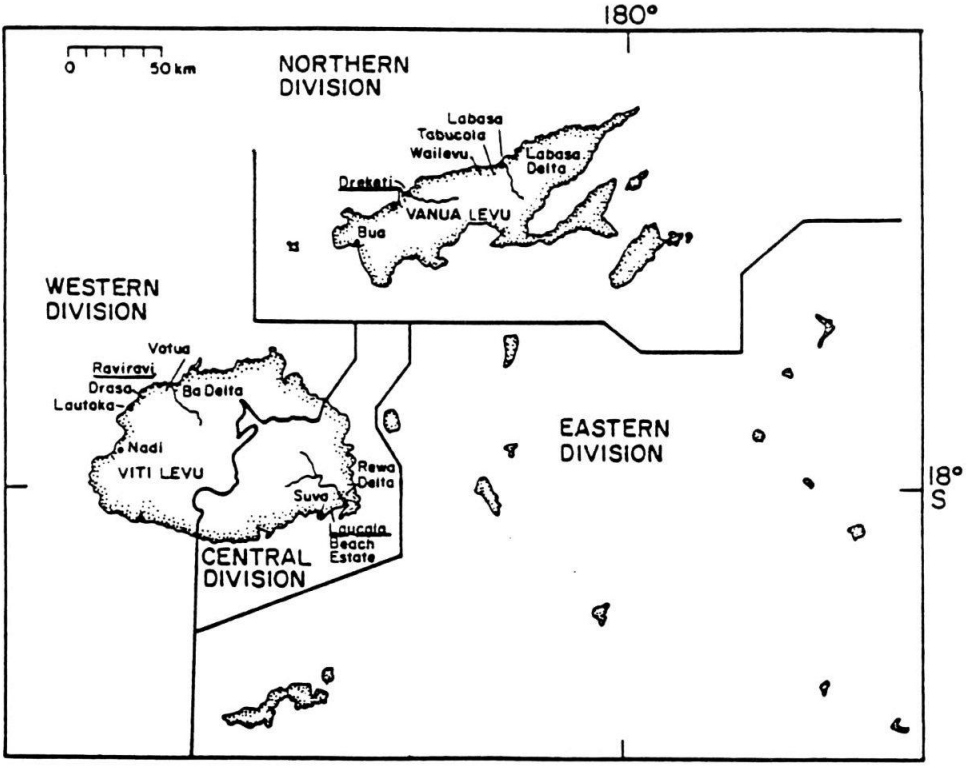
Further, in assessing development benefits, the ecological constraints of the mangrove ecosystem were not included in the economic BC analysis, though they have been acknowledged. Often, only the potential maximum yields of agricultural/aquacultural farming were used. This, for example, was the case in Fiji (Ernest 1983), India (Bandopadhyay 1985; Umali et al. 1987), Thailand (Aksornkoae 1985), and the Philippines (Ponnamperuma 1985).

In order to explicitly incorporate the effects of ecological characteristics of an ecosystem in a BC analysis, by defining the temporal and locational boundary of a project in terms of the underlying ecological processes, an optimal control theoretical framework is useful. Under the assumption of reversibility, conditions of linearity and constant prices, optimal levels of reclamation and of products such as fisheries and forestry harvest can be determined endogenously. The decision to reclaim or conserve is based on the current circumstances of the relative profitability (see Appendix).

The extended BC condition states that if the opportunity cost of not reclaiming mangroves today, which equals social interest rate times net marginal benefit of development, is greater than marginal benefits foregone in the form of fisheries, forestry, and environmental services, then the manager could reclaim mangroves, and the investment rate is positive. Moreover, if development were the optimal solution, then for each unit of reclamation the developers should compensate the losers by an amount equal to the marginal value of all the goods and services foregone. This is the weaker Pareto efficient criteria (Mishan 1976).

Conversely, if the marginal benefits of the <u>in situ</u> uses foregone is greater than those of development, then mangroves should not be reclaimed (i.e., investment rate is zero). Alternatively, the stock of the mangrove system should be allowed to grow with the result that reforestation is the policy.

Development projects that exemplify the most common reasons for reclamation in Fiji--i.e., for sugarcane and rice farming (Figure 1)--are examined, using the model just described. The study adopts an ecosystems approach that includes the spatial and temporal benefits as well as the costs of mangrove conservation and development. The underlying paradigm adopted in this economic analysis is the broader concept of "goods and services (functions) [as] provided by the (natural) environment" and not just "the use of natural goods with direct utilitarian benefits" (de Groot 1987).



•	City or town
Raviravi	Project area
————	Divisional boundary

Figure 1. Map of Fiji showing the three divisions examined in this study, project areas, and major cities.

After providing a background on ecology and institutional aspects of the mangrove ecosystem in Fiji (Section 2), the methodology adopted for the evaluation of net benefits is examined. Alternative approaches that are used to evaluate *in situ* and development benefits are discussed in Section 3. In Sections 4 and 5, the *in situ* uses of the mangrove ecosystem for its forestry and fisheries products are discussed and their marginal benefits evaluated using both income and compensation

approaches. Section 6 discusses the various alternative uses of reclaimed land in Fiji, such as for rice, sugarcane, and shrimp farming. In the evaluation of reclamation for rice, sugarcane, and aquaculture farming, spatial and temporal benefits and costs of the projects are included.

Finally, Section 7 compares the development net benefits and the benefits of the in situ uses of the mangrove ecosystem. Because of uncertainties about the effects of ecological factors and processes, and because some assumptions were made, sensitivity analysis relaxing the assumptions is undertaken and its policy implications are discussed.

The emphasis of the empirical application is the interdisciplinary analysis reflecting the interrelationship between the ecological processes and products on the one hand, and human needs and economic activities on the other. The third element, the institutional aspect, though often alluded to, is not discussed in detail. A knowledge of the institutional processes and the political economy of the mangrove ecosystem is important in understanding the reasons for and motives behind its management or mismanagement in Fiji, but this would require a separate study of its own.

SECTION 2

THE FIJI MANGROVES: A BACKGROUND

Mangrove ecosystems in Fiji, as elsewhere in the world, are generally associated with riverine/estuarine deltas and sheltered coastlines with low energy waves (Chapman 1977). On the two main islands of Viti Levu and Vanua Levu, mangroves cover an area of about 38,500 hectares (Watling 1985). Mangroves are also found on other smaller islands, but the extent of their distribution is not known.

Mangroves, found on the land-water interface, form the basis of an ecosystem comprising terrestrial and aquatic subsystems and do not constitute a homogeneous ecosystem. In Fiji, detailed scientific information on the fauna and flora associates of the mangrove ecosystem is scant; thus, an understanding about the food-chain relationships and specific physico-chemical processes within the coastal waters is almost nonexistent. Studies elsewhere in the world, however, have showed that a variety of different communities are found depending on the interaction between elements such as aridity, wave energy, tidal conditions, sedimentation, mineralogy, and neotechtonic effects (Jennings and Bird 1967; Oliver 1982; Thom 1982).

FLORA

Floristically, Fiji's mangroves are simple and dominated by three species and a putative hybrid--all belonging to the Rhizophoracea family (Richmond and Ackerman 1975). Also associated with mangrove forests are the boreti fern and four other commonly found tree species (dabi, saqali, sinu qaqa, and kedra ivi na yalewa kalou) (Table 1).

Table 1. Principal species of Fijian mangrove vegetation

Common name	Scientific names
Dogo*	Bruguiera gymnorhiza (L.) Lam
Tiri tabua*	Rhizophora stylosa Griff
Tiri wai*	R. samoensis (Hochr.) Salvoza Tomlinson, 1978
Selala*	R. x selala, Tomlinson putative hybrid of R. samoensis and R. stylosa
Dabi	Xylocarpus granatum Koenig
Saqali	Lumnitzera littorea (Kack) Voigt
Sinu qaqa	Excoecaria agallocha L.
Kedra ivi na yalewa kalou	Heritiera littoralis Dryand
Boreti ferns	Acrostichum aureaum

Source: Richmond and Ackerman (1975).

*Dominant species.

There are distinct zonation patterns and different alliances of dominant species, depending on the complex interaction of tidal frequency, heights of spring and neap tides, substrate types, and local geomorphology. Watling (1985, 1986), for example, distinguishes six generic plant communities or alliances with fifteen specific groupings from five locations. Generic alliances are categorized based on the standing biomass of the dominant species as delineated from the aerial photographs and limited ground survey (Watling 1985).

In the three deltas examined in this study, eight specific alliances dominated by either dogo or tiri species were distinguished. Mangroves of the Central and Northern divisions are floristically distinct from those found in the Western Division, because of the relative dry climate in the west. In the Ba Delta of Viti Levu, for example, only two alliances of tiri and selala are present, and both are dominated by two of the tiri species--R. samoensis and R. x selala--though some dogo

plants are found (Watling 1985). Earlier records (Sykes 1931), however, indicated dogo patches were present.

The mangrove plant species grow in intertidal areas. Different soils are found beneath the mangrove plants, depending on the origin of their parent material and local geomorphological process (Galloway 1982; Thom 1982).

SOILS

Six soil types have been identified as closely associated with mangroves in Fiji (Table 2) (MPI 1983). These mangrove soils, previously called "Saline Soils of the Marine Marsh" (Twyford and Wright 1965), can best be distinguished by their drainage conditions.

The dogo clay soil and the generally acidic tiri soil, both of which have no structure, drain very poorly and have high levels of exchangeable sodium and sulphides (MPI 1983). These two are considered true tiri soils. Dogo soils, which are neutral when fully saturated with water, become acidic when exposed to atmosphere. The dogo, tiri, and soso soils generally support healthy growth of R. samoensis, R. stylosa, R. x selala, and B. gymnorhiza in the project areas. The boreti, labasa, and dreketi soils generally have smaller growth of the tiri species; boreti ferns dominate the landward side on elevated grounds. In the agricultural project areas under consideration, soils belonging to the soso, dogo, and tiri series are dominant. Data from Indonesia (Hardjowigeno 1985) suggest that their soils--which are equivalent to soso and boreti soils, or Typic tropaquept, in Fiji--are highly suitable for rice crops, whereas sulfic tropaquept is moderately suitable. Typic sulfaquept (and Typic sufaquent, which becomes T. sulfaquept when drained) (Paramananthan and Eswaran 1984) are marginally suitable for rice crops and upland crops such as sugarcane (Hardjowigeno 1985).

Table 2. Mangrove soils of Fiji

Twyford and Wright's soil series	USDA soil taxonomy	Drainage condition
Labasa	Aeric tropaquept	Imperfect
Dreketi	Sulfic tropaquept	Poor
Boreti	Typic tropaquept	Poor
Soso	Typic tropaquept	Poor
Tiri	Typic sulfaquept	Very poor
Dogo	Typic sulfaquept	Very poor

Sources: Twyford and Wright (1965); MPI (1983).

Because of their similarity in soil type, response to drainage works, and potential for agricultural farming, these soils have been categorized into two groups: soso (which includes boreti, dreketi, labasa, and soso) and dogo (which includes tiri and dogo). The predominantly reclaimed soso soil can readily be used for rice or sugarcane production.

The nature of the soil types, the type of vegetation and physico-chemical process within the mangrove system, and climatic conditions determine the variety and density of fauna species in the mangrove ecosystems. The faunal communities extend from arboreal to epi and infauna as well as planktonic and nektonic (e.g., Clough 1982; Hutchings and Saenger 1987).

FAUNA

The critical importance of mangroves to the lives of many subsistence and commercially harvested fish and crustacean species has long been realized by the indigenous Fijians. In Fiji, commercial and subsistence inshore fisheries largely depend on the mangrove ecosystem. At least 85 percent of the species caught regularly among the mangroves are of food value to the

local people, whereas 80 percent are of commercial value (see Lal 1989a). The gross value of mangrove-associated fisheries products harvested commercially and for subsistence consumption in Fiji is about $31 million per year.

DEVELOPMENT PRESSURES

Mangrove land (i.e., the intertidal land where mangroves are generally found) is also under constant pressure for conversion to other nonrenewable uses. Most of the mangrove areas that have been converted (or reclaimed, as is generally known) in Fiji have been for agricultural purposes (Table 3).

Mangrove reclamation in Fiji began with the arrival of the Colonial Sugar Refining (CSR) Company, which was invited by the colonial government in 1882 to start a sugar industry in the colony. The first license to cut mangrove was issued to the CSR in 1886, and the first of the many reclamations by the company was started in 1896 when 486 hectares of mangroves in Tabucola in the Northern Division were approved. This was followed by an application for four other reclamations in the same division, further claiming about 1,200 hectares by 1900.

Despite a failure to meet one of the requirements of the initial lease to bring the reclaimed area under cane production within 7 years, the CSR was again issued leases to more mangrove areas at the turn of the century. Between 1896 and 1904, 2,334 hectares of mangroves were reclaimed by the CSR under fifteen different schemes (Table 3). Part of this area was salt marshland with boreti ferns, Acrostichum sp., but the extent of the boreti fern area reclaimed is not known.

The CSR used the same rationale as the government to reclaim mangrove land--to obtain land at a "peppercorn rent," which is a "mere nominal price compared with their real value" to avoid tackling the thorny issue of leasing native land (Lal 1989a). The CSR's main concern, which was also the concern of the Fiji

Table 3. Total reclamation for various purposes (1896-1986)

Agency/purpose	Area (ha)
Colonial Sugar Refining Company reclamation	2,334
Pre-1920 infill	56
Post-1960	
Government-initiated:	
Industrial and services	157
Agricultural	1,321
Agriculture excluding rehabilitation	1,159
Private sector:	
Industrial	19
Residential	31
Tourism	557*
Subtotal:	
Government	1,316
Private	607
Total, post-1960	1,923
Total 1896-1986	4,313

Sources: Compiled from various government records in the National Archives of Fiji, government department files (see Lal 1989a). The rehabilitation information was provided by Mr. A. Pepper, personal communication.

*Includes 440 hectares at Saweni Beach, approved in principle in 1983 but not yet developed.

Government in the past three decades, was to increase land under sugarcane. The Colonial Government, at the time of Cession, was keen to preserve as much of the lands in native hands as possible (France 1969). In fact, even today, indigenous Fijians hold inalienable rights to 83 percent of all the land in Fiji (Lal 1986).

Of all the reclamations since the turn of the century, the private sector (excluding CSR) initiated only 31 percent of the total (Table 3). Only 167 of the 557 hectares approved for private reclamation have so far been completed. The remaining area, which was approved for a single hotel development, has not been reclaimed because of a decline in the tourist industry but is expected to begin in 1990.

The majority of the reclamation has recently been initiated by various government agencies, primarily for agricultural purposes. Reclamation for industrial and service uses undertaken by the government accounted for less than 10 percent (157 hectares), of which about a third (55 hectares) was for sewerage oxidation ponds and treatment plants reclaimed specifically as a cost-saving effort (Green 1983).

Ninety-five percent of government-initiated reclamation has been for agricultural use (Table 3), specifically for sugarcane or rice farming on the two main islands. Except in regions of rehabilitation, more than 90 percent of the reclaimed area did not become productive within the projected 5 to 10 years, and a large portion are still barren.

INSTITUTIONAL CONTROL

Although the mangrove land and its plants are owned by the Crown, the ususfructus rights are recognized as belonging to the indigenous Fijians, the traditional fishing right (TFR) owners. The TFR is communally owned by a clan (mataqali) or a larger tribal group (the vanua or yavusa, depending on how these rights are identified and recorded by the Native Fisheries Commission. The nature and extent of proprietary rights over the coastal waters were disputed on many occasions throughout the colonial period (see Lal 1989a). Till today, the dispute has not been resolved (Council of Chiefs 1979). However, with the Cabinet decision in 1974 and the establishment of recompense procedure

for loss of fishing rights in the event of development in the mangrove/coastal zone, only the ownership of use rights currently lies with the Fijians (Lal 1983).

Although use rights are recognized as belonging to the Fijians, the nature of these rights is still unclear. The government policy itself has been contradictory: It had ruled that the TFR are not "compensable rights"; yet, it established the compensatory arbitration system explicitly recognizing the vanua concept of the traditional Fijian land-water ownership system (Lal 1983). The vanua system of the traditional ownership recognizes the continuity of, and interrelationship between, the land-based and coastal resources (Baines 1979). Because of this uncertainty, the TFR owners are not able to fully control uses or misuses of the mangrove ecosystem nor obtain adequate compensation for the loss of mangrove resources.

Although TFR owners regulate commercial fishing by non-TFR members, they generally do not monitor their own, nor do they control the logging activities by nonmembers within the mangrove forests. Mangrove uses, and that too only commercial ones, are controlled by the central government departments.

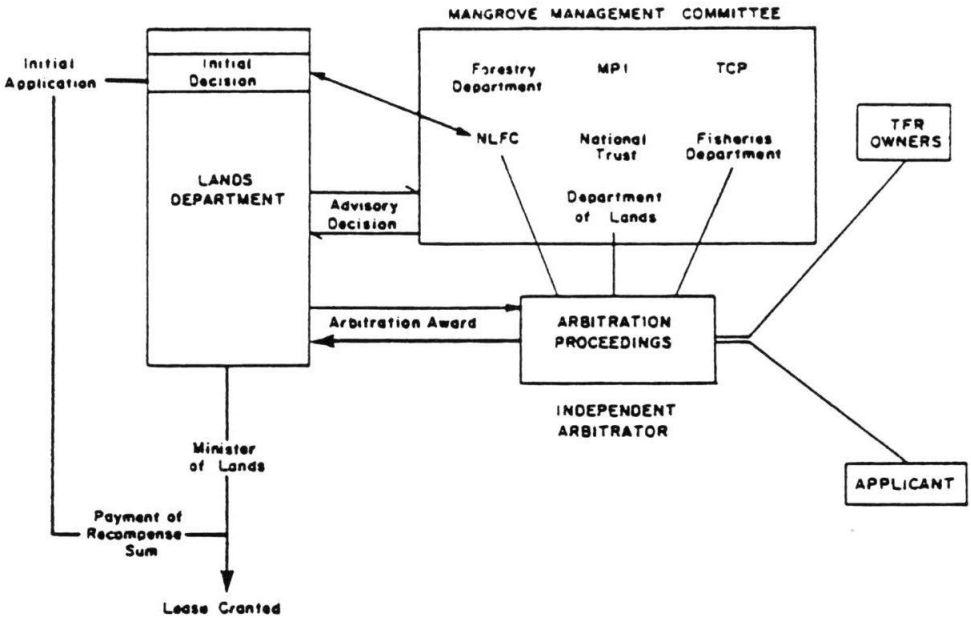
Because mangroves are found on land-water interface, their uses are not controlled by any one legislation or institution. Instead, a number of piecemeal, use-oriented laws separately govern the various resources, such as forestry, coastal fisheries, or land. These laws are a legacy of British legislative concepts that go against the traditional vanua system. The government agencies themselves undertook project evaluations within their individual sectoral goals without incorporating other environmental effects of the proposed development projects.

Commercial forestry licenses are issued and regulated by the Forestry Department under the Forestry Act, whereas fishing activities are controlled under the Fisheries Ordinance (Cap 135). The Crown Lands Act (Cap 132) outlines special provisions relating to foreshore land and soils beneath the waters and prohibits their use without a government lease (Jaffer 1986).

Decisions about forestry harvests have varied from time to time between licensed cutting of mangroves to total freeze, depending on the pressures put by different sectors of the communities. Similarly, reclamation of mangroves by the private sector has largely been controlled, while the government has been relatively free to develop them despite its stated policy of no large-scale reclamations in its Development Plans (Lal 1983). But, as previously mentioned, commercial fisheries are regulated by the TFR owners.

A commercial fishing license is issued by the government only after approval is obtained from the TFR owners and a permit is issued by the Divisional Commissioner. Some of the TFR owners have guarded their use rights jealously and at times have even resorted to violence to protect their interests. Because of complaints by the TFR owners about the loss of fisheries resources resulting from reclamation of mangrove areas in the late 1960s and early 1970s, a nonmarket institutional mechanism was established whereby the beneficiaries of a development were compelled to compensate the victims of reclamation (Lal 1983).

The Crown Lands Act and subsequent Cabinet decisions stipulate that the Lands Department is responsible for issuing a development lease for any activity relating to mangroves (foreshore, in general) (Figure 2). It does so only after mandatory institutional consultations have taken place between various departments, which serve on an advisory Mangrove Management Committee that was created in 1983. The Lands Department, which receives the development proposal, obtains the relevant information about the TFR ownership from the Native Fisheries Commission and forwards it to the independent arbitrator who then determines the value of the potential loss of fishing rights because of reclamation. The recompense sum is assessed based on submissions by the customary rights holders and developers and on information about the degree of productivity in the area provided by a government agency such as the Fisheries Department (Jaffer 1986). In making the assessment, the



MPI = Ministry of Primary Industries
TCP = Directorate of Town and Country Planning
NLFC = Native Land and Fisheries Commission
TFR = Traditional Fishing Right

Notes: Foreshore lease within city limits is finally issued by the TCP. Fisheries Department issues "inside demarcated areas" license after Divisional Commissioner issues a fishing permit approved by the TFR owners. Forestry Department issues forestry license on the advice of the Lands Department.

Figure 2. Administrative and institutional control of the mangrove ecosystem in Fiji.

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independent arbitrator considers the extent of use rights and the level of customary and potential uses (Lal 1983).

A development lease is issued by the Lands Department only after the developer has compensated for the potential loss of fishing rights. If the recompense sum proposed is not acceptable to the developer, then the area is not developed. On the other hand, if the proposed sum does not adequately reflect the

willingness to accept compensation by the mataqali, the TFR owners have the option to petition the Minister of Lands to stop development. The cost of the arbitration hearing, which averages about $500, is borne by the developer.

Since 1974, when the nonmarket transaction of the fishing rights was established, there have been 65 hearings on foreshore and mangrove reclamations for activities varying from jetty construction to large-scale reclamation for agricultural or urban uses. Mangrove-based hearings numbered 28, or 40 percent, of all the hearings for which the recompense awards have ranged from $54 to $3,211 per hectare. Since 1981, when there was a change in the independent arbitrator, and with that a change in the interpretation of the arbitration process, 21 reclamations of largely mangrove land and 17 developments involving other coastal foreshore and mudflats have been arbitrated.

SECTION 3

EMPIRICAL APPLICATION: METHODOLOGY

A number of different tools have been suggested for evaluating the net benefits and costs of using a natural resource (Sinden and Worrell 1979; Hufschmidt et al. 1983). In all cases, the quantities consumed and the actual or surrogate market price of the resource and other inputs or surrogate market price of their next best alternative are used. It is assumed that the demand for wetlands is the derived demand of goods and services that the ecosystem supports. In this study, the net benefits of various in situ uses of the mangrove ecosystem were estimated using the incomes approach, alternative cost method, and the nonmarket transaction of use rights.

IN SITU NET BENEFIT ESTIMATION

Incomes Approach

This approach has been the most commonly used technique for evaluating gross annual value of marshlands in the eastern coast of the United States (e.g., Pope and Gosselink 1973; Gosselink et al. 1974; Raphael and Jaworski 1979). A similar approach based on the use of mangroves for forestry, fishery, and recreational benefits has been used for mangrove wetlands in Fiji (Baines 1979; Watling 1985).

In these studies, however, it has been assumed that the value of the fish harvest depends only on the total wetland area, and the market price of fish was used to compute fisheries benefits. Similarly, the forest benefits are estimated using the market price of forestry products. Often it has been assumed that the entire value of fishery and forestry products is attributable to the wetlands, implying that the marginal values of labor and

capital in the fishing and forestry industries are zero. Moreover, these evaluations of mangrove benefits for fisheries products have failed to recognize the principle of "with and without analysis" (Hufschmidt et al. 1983). Specifically, since the fishes associated with mangroves are not unique to that ecosystem (Hutchings and Saenger 1987; UNDP/UNESCO 1987), the assumption that without the mangroves there will be no fisheries is not valid. Some fisheries will be viable provided there are other ecosystems such as those based on seagrass and coral reefs. Yet to evaluate just which fisheries would and would not be viable requires detailed research of specific ecosystems.

Thus, the fisheries benefits of mangroves are considered in terms of economic surplus (Hufschmidt et al. 1983), and the marginal value of incremental loss of products is used for subsistence or commercial consumption (Batie and Shabman 1982). In the absence of such information about the change in fish production in the "with or without" mangroves, sensitivity analysis using different factors derived from literature is appropriate.

The net present value of these annual net marginal benefits is then computed using a 50-year planning horizon and a social discount value of 5 percent, the average real interest rate for 1983 to 1986 (Bureau of Statistics 1988). Later, sensitivity analysis, varying the discount rate between zero (i.e., future is not discounted) and 10 percent and using a 100-year planning horizon, is undertaken to see the effect on the decision.

Alternative Cost Method

These estimates of fisheries and forestry net benefits do not include the value of other environmental services for which there are no direct market values. Shadow prices, in the absence of market prices, have often been imputed using other techniques. The value of waste filtering services provided by wetlands, for example, has been evaluated using the alternative cost method. The value of the filtering service was equated with the cost of

an alternative tertiary treatment plant (Gosselink et al. 1974). A similar approach has been advocated for estimating the value of services to protect against shore erosion (Hamilton and Snedaker 1984). This approach is used to evaluate the net benefit of filtering nutrients in partially treated sewage by mangrove soils.

The incomes approach and the alternative cost method, however, provide only a minimal estimate of the marginal value of the mangrove wetlands. Other values, such as the option value of future uses of mangroves and intrinsic values, which may not have utilitarian benefits, are not included.

Nonmarket Transactions of Use Rights

The transaction of use rights, at least in theory, could provide an estimate of the ecosystem value, which is greater than the sum of the use benefits. This was the case involving loss of coastal fishing rights in Tokyo Bay, where ususfructuary rights were well defined and individually owned (Hanayama and Sano 1981). This method is also used to evaluate the loss in benefits from mangrove resources after reclamation.

DEVELOPMENT NET BENEFIT ESTIMATION

Development net benefits can be evaluated by a number of different approaches using market prices of inputs and products (Sinden and Worrell 1979). An incomes or economic approach is used to evaluate development benefits (Squire and van der Tak 1975). The sum of expected stream of net benefits under perfect market conditions is equal to the market price of land (Barlowe 1973).

The net benefit of the reclaimed land is estimated using actual benefit and cost of rice and sugarcane/aquaculture farming. In the analysis, the initial capital cost of reclamation and the cost of the maintenance of drains, seawall,

and bundwalls are also included. In order to estimate the net income stream, models for sugarcane and shrimp productivity and rice productivity on the reclaimed lands in Fiji are developed using existing reclaimed land productivity data, experimental trial results, and comparable experimental results from other countries. This was necessary because the Raviravi and the Dreketi reclaimed mangrove lands, as will be discussed, have been almost unproductive. Further, the income stream from agricultural use of reclaimed land is a function of the desalination or "sweetening process," which itself depends on the type and quality of soils found in the project areas.

All of the financial market prices are adjusted for tax, subsidy, and foreign components using the Shadow Exchange Rate and financial to economic conversion factors for various inputs.

DATA SOURCES

In the empirical application of the extended benefit-cost analytical framework to the study of the economic and ecological interaction in the mangrove ecosystem in Fiji, a range of data sources has been used. For the historical information dating pre-1950, relevant government records at the National Archives of Fiji were the primary source, while more recent government records were used for analyzing the use of in situ mangrove resources and reclaimed land. Unless otherwise noted, most of the data are generated from government records, results of experimental stations, resource survey reports, and unpublished data collected by the government of Fiji in relation to various mangrove and nonmangrove-related projects undertaken from 1971 to 1987.

Some primary data were collected by the author. A preliminary forestry resource survey was undertaken along with an economic survey of representative licensed loggers and inshore fishermen operating in the Central Division. Interviewed were

two of the three licensed loggers and forty licensed fishermen. The informal interviews were guided by a questionnaire that focused on the costs and returns of the foresters' logging or the fishermen's fishing activities. Relevant secondary sources concerning the ecological and economic interactions within the mangrove ecosystem in Fiji also were consulted.

Numerical data were analyzed using Lotus 1,2,3. Only after the completion of the respective analysis were the estimates rounded off to reflect the degree of confidence. To avoid confusion, the figures were not rounded where estimates were used in intermediate steps. All estimates of costs and benefits are given in 1986 Fijian dollars, which were then equivalent to US$1.13.

SECTION 4

IN SITU BENEFITS: ECONOMICS OF FORESTRY UTILIZATION

In evaluating the net benefits of the use of natural resources, the volume consumed and the actual or surrogate market price of either the resource itself or its next best alternative are used. Where the use of the resource is largely for subsistence purposes for which there is no direct measure of the resource, a shadow value is arrived at by using the opportunity cost of the next best alternative.

MANGROVE FORESTRY USE

Today as well as historically, commercial and subsistence demand for mangrove products have largely been for fuelwood purposes. Dogo species have been commercially sought after specifically because of their clean burning properties and high calorific content--(4700 kcal/kg dry weight [Weisum 1977]). For subsistence purposes, however, the species most readily available have been used (Siwatibau 1978).

Present harvests of mangrove forests are undertaken for some commercial, but mainly subsistence, fuelwood purposes. Total mangrove fuelwood consumption in 1987 was about 40,700 cubic meters, of which subsistence harvests by rural and peri-urban harvest was 37,900 cubic meters; that is 93 percent of all mangrove fuelwood consumed in Fiji. On the other hand, commercial consumption of mangrove forests over the past 5 years (1982 to 1986) averaged 2,900 cubic meters, of which fuelwood accounted for about 96 percent, or 2,800 cubic meters (Table 4).

The total harvest of mangrove wood is about one-third of what 38,543 hectares of forest could support on a 40-year rotation cycle. A 40-year cycle is assumed in this study because of low

Table 4. Commercial harvest of mangrove wood

Use	1982	1983	1984	1985	1986
Poles	85	90	85	37	23
Charcoal	49	44	27	34	20
Firewood	2,584	2,776	4,374	1,526	2,775

Source: Computed from Fiji Government Forestry Department Records.

Units: Cubic meter of standing crop.

demand for mangrove fuelwood. In high demand and extensive silvicultural practice, a smaller cutting cycle of less than 25 years has been the norm (Hamilton and Snedaker 1984).

FORESTRY NET BENEFITS

The following economic analysis of forestry use is undertaken separately for the commercial and subsistence fuelwood harvest as their respective shadow values are different. Present day commercial uses of mangrove products for purposes other than fuel account for less than 1 percent of the total consumption (Table 4), and their economic contribution is not included in the present analysis, as is the net benefit of other subsistence uses of mangrove ecosystem (Table 5)--quantity and monetary value of which are not known.

Commercial Net Benefits

For the commercial consumption of mangrove forest products in Fiji, the market price and actual costs incurred in the harvest, transport, and marketing are used to evaluate the net marginal

Table 5. Traditional uses of Fiji's main mangrove species

Species	Uses
R. stylosa, R. samoensis, R. x selala	Firewood for cooking food, smoking fish, charcoal making; tannin for fishing net and line preservation; woody middle layer of prop root and aerial roots for stringing fish to facilitate their transport; prop and aerial roots for mud lobster, T. anomala, traps; bark to enclose crushed Sesarma sp. bait for mangrove crab trap; stakes for husking coconuts; aerial roots for plaited fish traps; timber for scaffolding buildings, tool handles, poles for fish traps, boats, fish fences, and fence posts
B. gymnorhiza	Firewood for cooking, smoking fish, cremation; timber for scaffolds, boat building, beams, rafters, furniture, tool handles, poles for fence posts, fish traps, boats; tannin for fishing nets and line preservation; stakes for husking coconuts; dye made from bark for hair, clothes, tapa clothes; during periods of food scarcity radicle of dogo seedling used as vegetable
X. granatum	Firewood, timber, fence posts, beams, poles, boat knees, medicine
L. littorea, H. littoralis	Firewood, timber, beams, poles, fence posts, poles for fish traps, cane making, medicine
E. aggallocha	Medicine for curing leprosy (Seeman 1873), medicine; sap regarded as poison; scented heartwood sought after for incense

Sources: Sykes (1931); Pillai (1987).

benefit of dogo. This information was obtained from informal discussion with two of the three concessionaires licensed to operate in the Central Division.

The average price of dogo sold in bulk to crematoria and squatter settlements (but excluding sales to secondary industries) is $6.30 per cubic meter (Lal 1989a). This does not include the retail price of dogo sold in small bundles of about 8

to 9 kilograms at 50 cents, which translates into a retail price of $71 per cubic meter. A small quantity (less than 5 to 10 percent) is sold in bundles to a largely urban elite. Nor does it include the retail price of dogo wood sold as charcoal, which is higher than the shadow price of wood in terms of kerosene equivalent of $52 per cubic meter. The average price of commercially sold dogo, $6.30 per cubic meter, is used as the marginal benefit of consuming fuelwood.

Cost of Commercial Harvest

Commercial harvest of dogo forests is undertaken using a chainsaw and three person-days per trip. Based on information provided by the two concessionaires, a concessionaire uses punts powered by a 25-horsepower outboard engine, consuming an average 150 liters of premix fuel per trip (Table 6). Using a three-person labor force, the concessionaire cuts about 10.6 cubic meters of dogo per trip. On average, the maximum number of trips possible is 120 in a year. Each trip involves harvesting at low tide, loading the firewood during high tide, and transporting it by boat to the concessionaire's home situated along the river bank. Therefore, if full use of the boat and chainsaw is made, the maximum potential harvest possible is 1,272 cubic meters (120 x 10.6 cubic meters).

This figure is used rather than the actual harvest made by the licensed concessionaire because, according to one concessionaire, the capacity production possible using present technology is 240 pyre loads of dogo a year. On average per concessionaire, however, the volume of fuelwood harvested is about half of this and depends on the demand. The average harvest is about 700 cubic meters per year per licensee. In order to calculate the net benefit from full use of forest products, the former figure would be more appropriate since at present there is excess capacity.

The economic trip cost is $2,682, whereas the financial trip cost per concessionaire per year is $4,800, with a capital cost

Table 6. Financial and economic costs and returns per forestry concessionaire

Cost of commercial harvest	Financial	Economic
Capital		
Punt (5-yr life)	420	424
Chainsaw (5-yr life)	620	682
Engine (25 hp and 5-yr life)	1,200	1,332
Per trip cost		
Premix	15	6.8
Labor 3 x $5	15	4.5
Transportation	10	11.1
Trip cost	40	22.4
Annual trip cost	4,800	2,682
Maintenance	403	447
Harvest per trip (2-pyre load)	= 10.6 m^3	
Annual harvest (10.6 x 120)	= 1,272 m^3	
Annual revenue ($6.3/$m^3$ x 1,272 m^3/yr)		= $8,014

of $2,438 every 5 years and an annual maintenance cost of punt, engine, and chainsaw of $403 (Table 6). Annual revenue of 240 pyre loads of mangrove wood at $6.30 per cubic meter is $8,014. These costs and revenues are assumed to be the same for all foresters in the three divisions. Because of species differences and the resulting differences in harvestable wood volume, however, the net benefits per unit area of mangrove forests are estimated separately for the three divisions.

With the potential harvest of 201 cubic meters per hectare of dogo forest in the Central Division (see Lal 1989a), this implies harvesting 6.3 hectares per year, or 253 hectares, over a 40-year cycle. Similarly in the West, with a potential harvest of 92 cubic meters per hectare, a concessionaire would need to harvest 13.8 hectares per year, or 552 hectares, over a 40-year period; in the North, the figure would be 186 cubic meters per hectare, a potential harvest of 6.8 hectares per year, or 274 hectares, every 40 years.

From the foregoing estimated benefits and costs per concessionaire who harvests mangroves in the Central, Western, and Northern divisions, the lump sum net present values (NPVs) of commercial use at a 5 percent social discount rate over a 50-year period are $225, $103, and $107, respectively.

Subsistence Net Benefits

Subsistence harvest of mangrove firewood is generally undertaken using a cane knife and punt. The cost and marginal value of harvesting mangroves for subsistence are not known. The opportunity cost of collecting firewood is to purchase inland wood or dogo from licensees.

For subsistence consumption, if mangroves are not available, the cost of the next best alternative would be derived from getting offcut wood from saw mills or by purchasing mangrove wood from concessionaires. With a cost of $7.20 per cubic meter for mill offcut timber and a transportation cost of $2, the net shadow value (net of transportation cost) of mangrove for subsistence users is $5 per cubic meter (S. Sutton, Department of Energy, pers. com. 1988).

Using an annual harvest figure of 37,875 cubic meters of wood harvested for subsistence (village and peri-urban) consumption and a shadow value of $5 per cubic meter, $189,375 is obtained as the annual net benefit. For a hectare of tiri land, which was estimated on average to yield 2.3 cubic meters per year, or 92 cubic meters, every 40 years as compared with 201 cubic meters of dogo wood, the subsistence net benefit is $11.50 per hectare per year; that gives a consumer surplus of $210 at a 5 percent discount rate over a 50-year period.

TOTAL NET BENEFITS OF FORESTRY USE

The present use of mangrove forests yields 40,684 cubic meters from 38,532 hectares or 1.06 cubic meters of fuelwood per

hectare of mangrove. This is on average 42.5 cubic meters per 40-year cycle, which is about 24 percent of the weighted average yield of 172 cubic meters per hectare (weighted over expected yields from dogo and tiri forests). Total annual harvestable forest on a 40-year rotation would yield 132,600 cubic meters of wood.

The potential yield of wood from dogo forest is approximately twice that of tiri land, although the net commercial benefits of dogo forests in the Central and Northern divisions are about the same as the subsistence net benefit derived mainly from tiri. The net commercial benefits are less than subsistence benefits only in the Western Division where no dogo alliance is found.

Over a 50-year period, the NPV per hectare of commercially harvested forest in the Central Division (assuming 1/40 of the managed forest is harvested annually) is $225; in the North, $207; and in the West, $103. Subsistence net return per hectare is $210.

Assuming that 43 percent of the mangrove area, which is the area occupied by dogo species in Fiji, is expected to be allocated for commercial use, and 57 percent for subsistence at full potential, the weighted NPV (rounded to the nearest ten) per hectare of forest would be $160 per hectare for the Western Division and about $210 per hectare for the North and Central divisions. The net benefits derived from the subsistence and commercial use of mangrove fuelwood--that is, on-site resource value--are less than 10 percent of the in situ fisheries net benefits, which is examined in the next section.

SECTION 5

IN SITU BENEFITS: ECONOMICS OF FISHERIES USE

HARVESTS AND CONSUMPTION

In Fiji, both the commercial and subsistence harvesting of fish and crustaceans largely depend on fishing activities carried out in the mangroves. More than seventy species of fish, crustaceans, and molluscs are caught regularly from the mangroves for food. In order to estimate the volume of mangrove-dependent coastal fishes harvested per unit area of mangrove forest, I have used only data from the Central Division. These data are the most reliable and are also considered at its optimum harvest level (Lal 1989a).

Commercial coastal (or locally known as IDA, "inside the demarcated area") fishermen, for example, in the Central Division spend about 70 to 80 percent of their time within the mangroves (Lal 1989a), whereas indigenous Fijians from villages in mangrove areas do almost all of their subsistence fishing there (Lal and Slatter 1982).

Commercial Harvest

Annual commercial harvest of mangrove-dependent species over 4 years (1984 to 1987) averaged about 2,394 tonnes, including 2,207 tonnes finfish and 187 tonnes crabs and prawns (Lal 1989a). The mangrove-dependent species accounted for about 54 percent of all the recorded weight of fish and nonfish sold through municipal markets and other outlets during 1984 to 1987. Although nationally the sale of mangrove-dependent fish and nonfish products has increased over the past 4 years, fish sales throughout the Central Division have leveled off at about 1,600

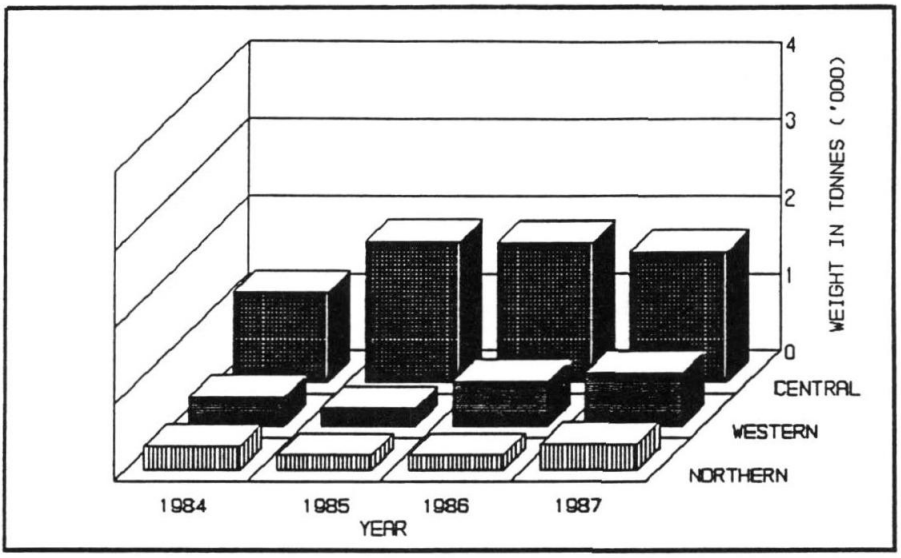

Figure 3. Sales of mangrove-dependent fish and nonfish products by division, 1984-87.

tonnes (Figure 3). Two-thirds of all fish and nonfish products sold nationally were marketed in the Central Division (Table 7).

Subsistence Consumption

Subsistence consumption of fisheries is extensive. The rural indigenous diet consists primarily of fish and nonfish products (Lal and Slatter 1982). The subsistence catches of finfish and crustaceans vary considerably by households. An average household took about three trips per week, 10 days a month, obtaining 3 kilograms of fish per trip (2 to 4 kilograms per trip), and 5 days a month collecting 3 kilograms of crustaceans such as kuka, (*Sesarma* sp.) or mana (*Thalassina anomola*). As finfishing or crustacean fishing is not done at the same time, on

Table 7. Total harvest of mangrove-dependent fish products by divisions

	Central	Western	Northern	Fiji
Subsistence	1,683	1,484	1,620	4,787
Commercial	1,343*	481	270	2,394
Total (t)	3,026	1,965	1,890	7,181
Mangrove area (ha)	9,136	11,822	17,586	38,543
Yield kg/ha	331			

*Figure is equal to 1,643, recorded minus 300 tonnes estimated to be sold in the division but caught elsewhere.

average 540 kilograms (15 trips/month x 3 kg/trip x 12 months) of fish and nonfish is consumed per year by each household. Based on the number of villages actually situated in the mangroves (the same ones which were included in the subsistence forestry survey), the annual subsistence consumption of mangrove-dependent fish and nonfish products is estimated to be 4,787 tonnes by 8,865 households on the two main islands (Lal 1989a).

The estimate does not include the amount consumed by Fijians who live in urban or peri-urban coastal areas and fish occasionally to supplement their diet. Also not included are Indian households that fish occasionally. The figure arrived at in this study is about 55 percent of Watling's computed value of 8,760 tonnes (Watling 1985). Watling arrived at this estimate by using 60 percent, a percentage by weight of 1983 sales of all commercially important species found in the Wairiki Creek survey (Lal et al. 1984), of 14,600 tonnes of subsistence consumption recorded by the Fisheries Division (Watling 1985). The Fisheries Division figures were estimates derived from a survey of all coastal Fijian villages, including villages on atolls and outer

islands. As discussed in the Appendix, coastal fisheries associated with mangroves is not unique to the system as the same species are also caught in coral and seagrass ecosystems. Thus, using total subsistence values would give an overestimation of the mangrove dependency. Another limitation of that survey was that the estimates were based on "subjective opinions of one person," usually the village chief (Fisheries Division 1979).

Total Fisheries Use

The annual harvest of mangrove-dependent fish and nonfish products for subsistence and commercial uses is about 7,200 tonnes (Table 7). This annual harvest is supported by a mangrove area of 38,543 hectares. As discussed, only the coastal fisheries in the Central Division are considered fully used. This is implied by the drop in commercial catches and the maximum use of existing technology by fishermen working within the institutional setting of permits issued by the traditional fishing rights owners.

The commercial production of mangrove-dependent fish in the Central Division is estimated to be 1,343 tonnes. This, plus a subsistence harvest of 1,683 tonnes, results in an estimated catch of 3,026 tonnes of fish and nonfish products produced by 9,136 hectares of mangrove area, or an average production of 331 kilograms per hectare per year at full use--that is, a commercial output of 147 kilograms per hectare, plus a subsistence harvest of 184 kilograms per hectare. This is below the range of potential sustainable fish yields of 800 to 10,000 kilograms per hectare expected from estuaries and lagoons with an aquatic primary productivity of 100 to 1,000 grams per hectare per year (Marten and Polovina 1982).

The quantification of the biological relationship between the reclamation of a unit area of mangroves and the foregone secondary/tertiary productivity in the form of harvestable fauna yield is not known (see Appendix). Thus, different scenarios, allowing for variation of 20 to 100 percent in the change in

fisheries yield, are used to evaluate the "with and without" fisheries marginal benefits foregone because of reclamation.

ECONOMIC NET BENEFITS OF MANGROVE-DEPENDENT FISHERIES

The annual harvest of 331 kilograms of fish and nonfish products supported by a unit hectare of mangroves is worth $864, if valued at the weighted average market price of $2.61. The economic value of the fisheries benefits foregone in the event of reclamation is estimated separately for the subsistence and commercial uses because their marginal net benefits to society are different.

Commercial Net Benefits

Estimates of the net benefits of commercial harvest of mangrove-dependent fish products are based on the fishing activities of the forty representative fishermen in the Central Division, where there are three classes of fishermen: Types I, II, and III (Lal 1989a). Type I fishermen fish for 3 to 4 weeks at a time, using large launches with small freezers on board and with two to three punts powered by outboard engines. They are based in the Central Division but fish mainly in the Northern Division. On the other hand, Types II and III fishermen fish exclusively in the Central Division and in fishing rights areas close to their home base. Type II fish 4 to 5 days a week, using half cabins plus outboard punts equipped with ice boxes. Type III are generally overnight fishermen who use punts with outboard engines and who use limited ice or none at all.

Information obtained from the Fisheries Division reveal that of the 203 registered inside demarcated areas (IDA) commercial fishermen in the Central Division, 141 fishermen (72 percent) fished in only one traditional fishing right area, while the rest had permits for two or more, usually contiguous, areas. Only

twelve of the sixty-two recognized mataqali waters in the Central Divison had more than five (seven to twenty-six) fishermen actually registed to fish there; seven had more than ten (eleven to twenty-six) permit holders and the rest had less than five registered commercial fishermen (Lal 1989a).

All commercial IDA fishermen generally use gill nets as their main gear. Limited handlining is done by fishermen who fish in mangroves, usually between setting the nets and picking up the fish. Types II and III fishermen generally use monofilament gill nets of three to four coils in length. Fishermen set their nets either during incoming or at high tides and pick up their nets at low tides. The nets are set in estuarine waters, particularly near mangrove areas or seagrass beds in the lagoons. Commercial fishermen interviewed spend 70 to 80 percent of their time within the mangrove areas.

Cost of Commercial Harvest

Annual trip cost as well as the initial capital cost is greater for the Type II than for the Type III fishermen (Table 8). Type I fishermen not only catch fish but also collect some fish from the villages. Because they fish in the Northern Division, they are not included in the following estimations of net benefit of mangrove-dependent fish harvested in the Central Division. Annually, a Type III fisherman on average catches 4,800 kilograms of fish, whereas a Type II fisherman catches 9,200 kilograms. These catches include fish given as in-kind payment to the laborers on board. The 1987 weighted average price of fish and nonfish products sold through the municipal markets and other outlets in the Central Division was $2.61 per kilogram for mangrove-dependent fish products (Lal 1989a).

Assuming that the technology remains constant and that the catch is maintained (which is more likely to be the case because of the traditional fishing rights institutional arrangement), the present value of net economic benefit per kilogram of fish caught using Types II and III vessels over a 50-year period is positive.

Table 8. Average financial costs of types II and III fishermen

Cost	Type II	Type III
Trip cost		
Per trip	282	51
Annual financial	11,280	6,090
Annual economic	6,722	3,408
Maintenance		
Financial	1,770	623
Economic	1,965	692
Initial capital		
Financial	25,045	2,995
Economic	24,746	3,240
Total annual catch (kg)	9,200	4,800
Annual revenue	23,920	12,480

Source: Fisheries Survey, April-May 1988 (Lal 1989a).

The weighted average lump sum value of benefit foregone for a kilogram of fish caught commercially is $17.70, if a 100 percent decline occurs. This estimate is based on the assumption that the economic value of labor is 30 percent of the actual financial cost. The actual financial net benefits would be considerably less.

Subsistence Net Benefits

The shadow marginal value (i.e., the shadow price of mangrove-dependent fish for subsistence purposes) is taken as $1 per kilogram. This is the average price paid by commercial fishermen when they buy surplus fish from villagers in rural areas away from markets. Government fish collection vessels also purchase fish from rural Fijians at this average price (Fisheries

Division, pers. com.). Thus, the opportunity cost of subsistence consumption is the income foregone if the catch were sold.

A typical rural household of 5.8 members consumes an average of 540 kilograms of fish and nonfish products per year. Therefore, using the shadow price of $1 per kilogram, the total benefit of subsistence consumption would at least be $540. The average cost of subsistence fishing is $50 in gear such as lines and hooks and about $30 in miscellaneous expenses such as bait and benzine for lights.

The net benefit of subsistence fishing per household is $460 per year. The net present value (NPV) of an annual consumption of 540 kilograms of fish products over a 50-year period at a 5 percent social discount rate is $8,397. But if mangroves were to be reclaimed, the lump sum value of foregone benefits would be $15.60 per kilogram of fish harvested annually over the next 50 years. With 184 kilograms per hectare of subsistence harvest, the NPV per hectare would be $2,862.

Total Fisheries Net Benefits

Using the values of subsistence and commercial harvests of mangrove-dependent fish and nonfish products derived earlier, the NPV of the mangroves in terms of foregone net benefit from the harvest of fisheries products is about $5,468 per hectare. The total present value of the *in situ* benefit stream of fish products for subsistence harvests is $2,862, which is about the same as the net benefit ($2,606) derived from commercial harvest.

Assuming that as each unit area of mangrove was reclaimed there was a proportionate decline in the harvestable volume of fish, the net value of fish lost per hectare would be $5,468 over a 50-year period, or an annual loss of $300 per hectare. As discussed earlier, the quantified functional relationship between the dependent fisheries and the mangrove forest area is not known. The preceding estimate is based on the assumption of a 100 percent decline in the optimum yield in fisheries products. The fisheries' annual marginal benefits per hectare range from

$60, assuming a decline to 20 percent of the original harvest, to $240 if it declined to 80 percent of the original yields. Conversely if the productivity of the mangrove areas ranged between 20 and 80 percent, annual marginal net benefits would vary between $60 and $240 per hectare.

IN SITU BENEFITS

Other Services

Other benefits, such as nutrient filtering services and existence value, are difficult to estimate, as there are no direct market values. Using the alternative cost approach, an estimate of the nutrient filtering services of the mangrove soils gives an average benefit of $106,250 per hectare over 50 years. This value is obtained from the difference between the cost of a conventional treatment plant and the use of mangroves for oxidation ponds. The cost of secondary treatment of sewerage using a conventional treatment plant was approximately $2.5 million, whereas the use of oxidation ponds using 32 hectares of mangrove land for the treatment of comparable sewerage volume cost $0.8 million with minimal or no energy inputs and low maintenance (Green 1983). Therefore, the average benefit of mangrove soils' filtering capacity is $106,250, which gives an annual benefit of $5,820 per hectare. This figure needs to be treated with caution, as it represents the average and not the marginal value--the value used in economic analysis. The difference between the two would be significant where large areas of mangroves are present.

Because the incomes approach is used in this study, other values, such as the option value in knowing that the mangrove system exists and can be used in the future (Cicchetti and Freeman 1971; Bishop 1982), are not captured. Also not captured are ecological benefits that have intrinsic but not utilitarian values. Thus, the foregone net benefits from marginal loss of

fisheries and forestry products are the absolute minimum estimates of the benefit that a society receives from a natural and dynamic mangrove ecosystem.

In theory, as discussed earlier, transaction of property rights can capture tangible as well as intangible benefits (Bergstrom 1976), as was the case in Japan (Dixon and Hufschmidt 1986).

Estimation Using Compensation Approach

The loss of fishing rights in Fiji caused by the reclamation of mangroves has been compensated for by the developers. As discussed, the recompense sum is determined by an independent arbitrator within a nonmarket institution. In the absence of a perfect market mechanism for the transaction of rights, nonmarket transaction, within a given institutional framework, could be used as a proxy for market allocation (Cheung 1970). Thus, in this study it is assumed that the recompense values arrived at in the arbitration hearings reflected the amount that the traditional fishing right owners were willing to accept, given the current property rights arrangement in Fiji. This assumption is both valid and reasonable, as the government that set up the institution of arbitration was, in fact, dominated by representatives of the Fijian landowners. Furthermore, the mechanism was set up specifically to compensate for the loss of indigenous rights and benefits after the Fijians expressed concerns about such losses (Lal 1983).

There are arguments for and against the efficiency goals of the legal systems just as there are arguments for and against the infallibility of the market systems (e.g., Knetch 1983; Hufschmidt et al. 1983). However, despite the criticism that everyday decisions of tribunals and governments do not always have goals of efficiency and fairness, the overall legal rules are generally consistent with efficiency considerations (Posner 1979).

During 1981 to 1987, the average recompense sum per unit hectare of reclaimed mangrove land was $1,099 for industrial uses and $518 for nonindustrial uses. However, there is a large variation in the awards, as indicated in Table 9.

Recompensation awards cannot be explained in terms of area of mangrove land, population size, and productivity or alternative uses--factors that the arbitrator was mandated by a Government Cabinet decision to consider while assessing the recompense sum (Jaffer 1986). Using dummy variables and ordinary least square regression analysis, the R^2 value obtained was only 0.094 with 34 degrees of freedom. Furthermore, the awards could not be explained in terms of regional differences. Within 90 percent confidence limits, there is no significant difference in the mean recompense sum awarded per hectare between the three divisions (Lal 1989a).

The large variation in recompense sum may be due to what Barlett (1973) has called the "political market failures," where preference is given to some groups and not to others. The relative militancy of some traditional fishing right (TFR) owners and their differential access to political power may have played a major role in the arbitration process. In this study, it was observed that the recompensation sum per unit area reclaimed was the highest where the TFR owners were extremely political. For example, for the reclamation of 11 hectares of productive mangrove system for a sewerage treatment plant in the Ba Delta, the highly political Votua fishing right owners (one of the members was then a government minister) were able to obtain payments of $2,964 per hectare in 1985. In contrast, in other areas during the same period, the awards in current dollars for nonindustrial reclamations ranged from $49 to $670 per hectare. Similarly, the adjacent vanua of Vitogo, within the Ba Province, were able to obtain $4,458 per hectare in 1981 for 1.1 hectare of foreshore reclaimed for wharf construction.

These TFR owners have a history of defending their traditional fishing rights. For example, Votua fishing right

Table 9. Recompensation awards (1981-87)

System	Use	Mean ($/ha)	Standard deviation	Range ($/ha)	Median	Mode
Mangrove (21)		801	957	54 - 3,211	296	126
Mangrove	Industrial	1,099	898	126 - 3,023		
Mangrove	Nonindustrial	518	884	54 - 3,211	296	126
Foreshore (17)		1,134	1,513	27 - 6,242	543	6,242
Foreshore	Industrial	1,309	1,618	57 - 6,242		
Foreshore	Nonindustrial	712	890	27 - 2,470	543	6,242
Mangrove/ foreshore	Industrial	1,213	1,343	57 - 6,241		
	Nonindustrial	578	890	27 - 3,211		
ALL areas:						
Central (15)		817	919	27 - 3,211		
Western (16)		1,191	1,524	54 - 6,242		
Northern (7)		684	801	68 - 2,470		

Sources: Compiled from various government records (see Lal 1989a).

Notes: 1986 prices. Total number of awards in each category is given in brackets.

owners refused to allow the Colonial Sugar Refining Company to reclaim all but about 330 hectares of a 4,000-hectare mangrove area in the Ba Delta applied for and approved by the government as early as 1900. Even in more recent periods, they have been vocal and protective of their fishing grounds and fishing rights (Lal 1989a).

Since the recompense sum is supposed to reflect the present value of benefit stream in perpetuity, the average annual recompensation at a 5 percent social discount rate is $60 per hectare for industrial use and $30 per hectare for nonindustrial use. These are lower than estimates derived from the incomes approach. However, if we use the maximum values (in 1986 prices) awarded for the mangrove reclamation in the Ba Delta, a recompense value of $3,211 per hectare would be awarded. This is the same as $2,898 derived from a forestry loss of $160 per hectare in the Western Division and a fisheries loss of $2,734 estimated using the incomes approach and assuming that a marginal decline of 50 percent in the fish yield results from reclamation. That is, a minimum value of mangrove ecosystem in Fiji is at least $3,000 per hectare under the present supply and demand of forestry and fisheries products, and the existing market and institutional organization. As noted, other in situ and intrinsic values are not included in this minimum estimate.

Nevertheless, even if we take the lower recompense values as reflecting the marginal net benefits foregone in terms of fisheries resources alone, one could not justify a number of reclamations that have already been undertaken in Fiji.

SECTION 6

DESCRIPTION OF TWO SCHEMES

Conversion for agricultural uses has been the main reason for the loss of valuable mangrove ecosystem in Fiji. Projects with and without irrigation have claimed more than 4,000 hectares of productive mangrove land (Table 3). Ninety-five percent of government-initiated reclamation has been for sugarcane and rice farming.

The reclamation of mangrove land for agricultural use involves clearing of mangrove trees and construction of seawalls, sluice gates, and tidal structures to stop tidal influx. It also requires construction of drainage systems to accelerate drainage, replacement of sodium ions, and leaching of salts until salinity is reduced to levels tolerable to crops concerned. For irrigated schemes, the process further involves construction of irrigation canals and storage ponds and flooding of soils.

Here, as examples of the agricultural uses of reclaimed lands and their relative successes (or failures), two schemes are examined in the context of the preceding theoretical model. One involves rice farming, the Dreketi Rice Irrigation Project, and the other sugarcane farming, the Raviravi Sugarcane Project. These particular projects were chosen because each of them was the largest development completed in their categories. The agricultural projects chosen are also the first reclamations undertaken by the government of Fiji, thus allowing for desalination of the reclaimed land to be reflected in the productivity of the farms.

The Raviravi Sugarcane Reclamation Project, which involved only drainage works, began in 1971, whereas the Dreketi Rice Irrigation Scheme, which had both drainage and irrigation, was

started in 1972. They also are examples of reclamation with and without irrigation--an important factor in the desalination process.

The projects have not fulfilled the expectations of their planners. Despite claims that reclaimed lands are highly productive (Ernest 1983), more than 90 percent of the reclaimed area did not become productive at all within the projected 5 to 10 years. The only areas that did become productive within that time frame were the old Colonial Sugar Refining Company reclaimed land (reclaimed more than 60 years ago), which had gone out of production because of leakage in the seawalls.

Fifteen years after the schemes were started, only a small proportion of reclaimed area was under irrigated double-crop rice production. On the other hand, actual mangrove areas at Raviravi and others such as at Penang and Drasa, which were reclaimed by drainage only (i.e., without any irrigation), have been almost completely unproductive (Sugrim 1988).

When the Raviravi project was started, the reclaimed area was expected to come under production within 3 to 4 years (Livingston n.d.). In 1984, it was projected that Raviravi could be productive after about 10 to 20 more years (i.e., after 25 to 35 years of leaching by natural rainfall). The Dreketi reclaimed area is expected to become fully productive after 20 years of reclamation (Reddy 1988, pers. com.).

Generally, the reclaimed area is not expected to come under production, both for sugarcane and rice, for at least another 7 to 10 years, depending on the drainage and leaching of salts (Kafoa 1983, pers. com.). As explained in the next section, the time required to make the reclaimed land productive depends on the soil pH and the rate of the salt-leaching process, which are functions of the nature of soil types present as well as natural rainfall or irrigation. Readings greater than two milliequivalents of 20 percent exchangeable sodium levels are generally considered very high for agricultural farming in Fiji (Lal 1989a).

RECLAMATION WITHOUT IRRIGATION

Raviravi Reclamation: Sugarcane Production

In Fiji, reclamation without irrigation has largely been undertaken for sugarcane production, which is the mainstay of the economy. Mangrove reclamation was reinitiated after more than 60 years "to make available land for Fiji's rural population" under the Fiji Development Plan VI (Livingston 1973). The Raviravi area was chosen for reclamation because of its "good natural drainage, small mangrove areas and bay shape and easy access." It was expected to support sixty farmers.

Initially the project was started using local funds. But later, as a subproject of a World Bank-funded Sugarcane Extension Development, the Sugarcane Drainage Improvement Project involving drainage and seawall construction was commenced in 1976.

Through the Sugar Development Project, 216 kilometers of main drains and associated works, 56 kilometers of seawall, and 39 outfall structures were completed, covering 37 schemes and benefiting about 13,000 hectares of low-lying cane lands. Since 1968, agricultural reclamations involved 1,321 hectares of reclamation/rehabilitation. Of this number, 790 hectares of new mangrove areas were reclaimed for cane cultivation. The Raviravi scheme alone accounted for 365 hectares, or 46 percent. The rest was distributed over 12 schemes in the Western and Northern divisions.

The Raviravi reclamation process involved clearing mangroves and constructing bund wall and seawall. Rainwater was used to flood the area to initiate the leaching process, which was slow and almost ineffective because of the seasonality of the rains. Furthermore, the costs of bringing the reclaimed area under production kept increasing.

Reclamation Cost. The exact cost of the Raviravi scheme is not clear, as there were many duplications of construction works, and the project was divided into two subprojects: 282 hectares

available for sugarcane and another 67 hectares allocated for marine shrimp aquaculture. Furthermore, records were poorly kept, primarily because two separate departments--the Department of Drainage and Irrigation (DI) and the Lands Department--were involved during different phases of the project, which took 10 years to complete.

By 1982, the Lands Department and the DI incurred expenses of $1.6 million. For this analysis, the reclamation cost was an estimated $1.2 million, because some of the post-1982 capital works were considered reconstructions to rebuild parts of the seawall damaged by mud lobster and to rectify maintenance problems caused by the lack of institutional coordination. These costs could have been avoided had the seawall been properly maintained. Thus, the maintenance cost of $7,516 since 1982 is included in the analysis. Part of the reason for the duplicate costs was that both agriculture and aquaculture were very unproductive.

Sugarcane Productivity. There is no substantial production of sugarcane from the Raviravi reclaimed area or from about 600 hectares of other new reclamations (Sugrim 1988). Some areas, such as Wailevu and the mudflats on the periphery of the Raviravi, have come under cane production, but these have largely been on soso clay (Typic Tropaquept) soils.

The main cropping pattern proposed for Raviravi was sugarcane cultivation with 2 to 3 years of initial fallow period (Fiji Times 1971). The Fiji Sugar Corporation's trial within 3 years of reclamation (i.e., within the projected period of full production) was a failure. Subsequent plantings and addition of organic millmud produced better results, however, as they helped to decrease the sodium content and improve the soso soil structure. By 1977, yields of 13 to 21 tonnes per hectare with different commercial varieties of cane were obtained (Sugrim 1988), but this was still below the expected yield of 70 tonnes

per hectare achieved on Tabucola soils, which had been reclaimed at the turn of the century.

The areas of uncultivated soso soils showed little decline in the sodium content in the top 30 centimeters of soil. By 1981, the sodium content had declined to only 25 percent milliequivalent, which was 5 percent higher than what is considered suitable for agriculture. Soils containing such high levels are not farmed. But dogo soils belong to a group known as acid sulphate soils, Typic sulfaquepts, and are much more difficult to use as they contain high levels of pyrite, which oxidizes to sulfuric acid when exposed to atmosphere. Furthermore, these acid sulphate soils are high in aluminum and iron, which are also toxic to plants (Moormann and Pons 1975). At Raviravi, soso soils comprised less than 20 percent of the reclaimed mangrove areas; the rest were dogo soils (Lichatowich 1978).

Despite the availability of new salt-resistant cane varieties, the Raviravi scheme still was not under production 17 years after its inception. Similarly, other land reclaimed in the late seventies at Penang and Drasa in the Western Division also lay barren.

Raviravi land could eventually obtain the Land Use Classification of IIw. The Colonial Sugar Refining Company-reclaimed Tabucola soils have been so classified and are often referred to as "a success story," with a maximum yield of 70 tonnes per hectare for some Tabucola farms (Ellison and Sugrim 1983). The soils at Tabucola, however, are not the true dogo or tiri soils found on most of the recently reclaimed soils (Lal 1989a).

Reclaimed dogo soils at Raviravi under the natural leaching process are expected to require 35 to 40 years to produce 56 tonnes per hectare of sugarcane. This projection is based on the assumption that 5 tonnes per hectare, the amount produced at the Wailevu scheme after 5 years, was possible within 10 years of leaching of dogo soils at Raviravi. The latter figure was

derived from the natural leaching rate recorded by the Fiji Sugar Corporation Research Station (Ellison and Sugrim 1983). This projection was based on results of sugarcane farming on more recently reclaimed mangrove soso soils (Wailevu Project), experimental trial results of Raviravi, and the assumption that regular plowing was done and drains were maintained. The expected incremental increase in sugarcane yield is about 2 tonnes per hectare after reaching 30 percent exchangeable sodium level (Valvidia and Pinna 1980). Exchangeable sodium levels below 10 percent have little or no deleterious effect on cane yield (Valvidia 1977).

When salinity has declined to acceptable levels, saline farms have to be managed differently from nonsaline farms. The main difference in farm management practice involves the liming and ridging of saline soils for the cane roots to remain out of saline water, and shallow plowing to prevent acid sulphate conditions from developing. Thus, costs of saline farms are higher than those of nonsaline farms.

Saline Farm Costs. Sugarcane farming involves a management practice of new and ratoon cropping, where 25 percent of land available is planted with a new crop while the rest remains under first or second ratoon. On the assumption that this cropping pattern is practiced and that recommended farm inputs and their unit prices are applied, the out-of-pocket financial cost of farming 1 hectare of saline land would be $519 as compared with $444 for nonsaline soils (Table 10). Furthermore, to become productive by year 10, saline soils would require constant work, input of mill mud, and regular plowing and cultivation to build the soil structure. This practice would add about $100 per year to the cost of maintaining a seawall, drains, and canals.

But economic costs, which include subsidies for fertilizers and other chemicals and the family labor valued at 30 percent of the wage rate, were estimated to be $640 per hectare for saline farms and $497 per hectare for nonsaline farms (Table 10).

Table 10. Financial and economic costs per hectare of saline and nonsaline reclaimed mangrove farms with assumed cropping practice of 0.25 hectare of new planting and 0.75 hectare under ratoon

	Financial	Economic
Saline soils		
Seed cane @ 5 t/ha @ $27.67/t	35	35
Land preparation and cultivation	161	179
Fertilizer	225	340
Herbicide	23	38
Family labor	134	40
Overhead	9	9
Rent	66	
Out-of-pocket cost	519	
Economic cost with opportunity cost of labor taken as 30%		640
Nonsaline soils		
Seed cane @ 5 t/ha @ $27.67/t	35	35
Land preparation and cultivation	136	149
Fertilizer	175	264
Herbicide	23	38
Family labor	127	38
Overhead	9	9
Rent	66	
Out-of-pocket cost	444	
Economic cost with opportunity cost of labor taken as 30%		497

Note: Figures have been rounded to the nearest dollar.

Because harvest and transportation costs depend on the volume of cane produced, these are not included in the estimates; however, they average $8.15 per tonne.

With an average cane yield of 56 tonnes per hectare and a cane price of $28 per tonne, nonsaline soils would produce a gross revenue of $1,568 per hectare, as compared with $140 per hectare after 10 years from reclaimed dogo soils. The cane price of $28 per tonne is the 9-year average price for 1977 to 1986, excluding 1983--the drought year (Bureau of Statistics 1988). The sugarcane price is the farmers' actual cane price given under

a formula awarded by Lord Denning in 1969, which settled a contract dispute between the farmers and the sugar mill (Denning 1970).

Under full production, mangrove reclaimed soils and nonsaline farms would on average give the same cane yields and returns; saline soils, however, would take more than 30 years.

Raviravi Reclamation: Aquaculture

Only 67 hectares of the 350 hectares of Raviravi reclaimed area was put to aquacultural use after the initial experimental trials were carried out from 1972 to 1978. The initial experimental demonstrations on twelve ponds with 7 hectares in total surface area were undertaken by the Fiji Government with the assistance of FAO/UNDP funds and personnel (Lichatowich 1978). Different fish and shrimp varieties were used to determine the feasibility of using reclaimed mangrove areas for aquaculture in Fiji. Despite problems with low pH and acid sulphate soils, aquaculture on reclaimed soils was considered viable and "appeared to have economic potential" (Lichatowich 1978). Net financial returns of $3,200 per hectare per year were estimated, using the highest yield obtained from a polyculture of yawa or milkfish (Chanos chanos) and shrimp (P. monodano) from one of the trial ponds of 0.6 hectare.

The assumption underlying the economic viability was that the mangrove soils were not acidic (Lichatowich 1978). This assumption of nonacidic conditions was grossly mistaken, for acid sulphate conditions not only make aquaculture uneconomical but also make reclaimed mangrove land uneconomical.

Based on these trials, commercial joint ventures with the France Aquaculture, a subsidiary of the Centre National D'exploration Des Oceans, began in 1981. Culture of only two shrimp species (P. monodon and P. stylirostris) was undertaken in a 24-hectare pond. The project was then developed in two stages.

The farming practice involved the use of ponds, the average size of which was 2 hectares in surface area and 1 meter in depth. These ponds were compacted with earth dikes and 10 percent of pond water was renewed daily by electric pumps (Lal 1989a). Intensive farming was possible with the post-larvae produced in a hatchery from captive brood stocks. Initially, the post-larvae were produced using a portable hatchery that also provided the feed for the grow-out stage. These inputs were expected to be replaced in time by locally produced feed and post-larvae. At full production, the project was expected to produce two crops of prawns with an average yield of 1.25 tonnes per hectare per crop (Fiji Government records; see Lal 1989a). Because the project was undertaken in different phases, the costs were also duplicated in some cases.

Capital Development Costs. The actual expenditure for the aquaculture project totaled $228,233 for 1973 to 1978. The accumulated capital assets at the beginning of the joint venture in 1981 were valued at $217,342 (1986 dollars). With the expansion of pond area and other buildings in 1982 to 1984, an additional capital cost of $275,000 was incurred. The operating cost for the 24-hectare pond was based on the project proposal submitted to the government of Fiji by France Aquaculture.

For this study, it is assumed that the post-larvae are reared in Fiji, feed is produced locally, and local professional staff are used. The yield figures used for 1982 to 1987 were derived from the actual annual production of two crops from the 24-hectare pond. Post-1987 estimates were based on a potential yield of 1.8 tonnes per hectare per year and not 2.5 tonnes per hectare per year as projected by France Aquaculture, but assumed to be attained from the present yield of 0.35 tonne per hectare per year within 5 years.

Considering the present yields, the acid sulphate soil conditions found in the Raviravi reclaimed soils, and the water problems faced, the yield of 2.5 tonnes per hectare per year

is considered on the higher side when compared with the same species yield from other countries. In Cochin backwaters, for example, where aquaculture practices go a long way back, an average yield of 0.9 tonne per hectare per crop was obtained from intensive farming of P. indicus (Vanucci 1984). In Taiwan, where the aquaculture farmers are generally acknowledged to have advanced knowledge of aquaculture, shrimp yields of 1.4 tonnes per hectare per year were reported (Chen 1976). Nonintensive (i.e., extensive) shrimp yields are much lower in other Asian countries with many years of aquaculture experience, using a natural supply of seeds from water taken into the ponds. In Thailand, for example, the yields have ranged between 190 and 310 kilograms per hectare per crop (Saraya 1984).

Thus, the Raviravi project is analyzed with the assumption that 0.9 tonne per hectare per crop or 1.8 tonnes per hectare per year is achievable in the Fiji ponds. Later, this assumption is relaxed to see its effects on the net benefits estimate.

Total Raviravi Net Benefits

With an annual harvest of 56 tonnes per hectare of sugarcane achievable within 30 years after completion of the reclamation (1978) on 282 hectares of reclaimed land, and a projected shrimp yield of 1.8 tonnes per hectare from the 24-hectare actual pond area, the net present value (NPV) of the net development benefits from the Raviravi project as a whole is negative $3.3 million (Table 11). With inclusion of the foregone net benefits stream of the fisheries and forestry products harvestable from the ecosystem, the total net benefits are negative $4.3 million.

The foregone NPV of the fisheries benefit of $957,000 for the Raviravi project is based on the assumption that the marginal effect of reclamation on the fisheries output is 50 percent of the original harvest, while the cost of harvest does not change. Only the catch and thus the revenue change.

Using the multidisciplinary approach advocated in this study for project evaluation, I found the agricultural use of reclaimed

Table 11. Net benefits of the Raviravi Project

Type of benefit	NPV lump sum	Annual opportunity cost
Development	-3,295,000	-181,000
In situ fisheries	957,000	52,000
In situ forestry	57,000	3,000
Total	-4,310,000	-236,000

Note: Figures have been rounded to the nearest thousand.

land without irrigation is not economically viable even without taking into account the in situ benefits of mangroves foregone. The next section shows that contrary to what has generally been said about the viability of agricultural uses of reclaimed land where irrigated water is available (e.g., Law Wei Min 1985; Aksornkoae 1985; Hardjowigeno 1985), reclamation for agricultural use is not always economically viable. This is demonstrated by a detailed analysis of an agricultural development where irrigation is available and is expected to increase the desalination rate.

RECLAMATION WITH IRRIGATION

Dreketi Rice Scheme

Only the Dreketi Rice Scheme used irrigation for rice farming on reclaimed mangrove land. The Dreketi Scheme accounted for 45 percent of all reclaimed mangrove areas proposed for rice growing. The rest included two schemes, one of which was already completed without irrigation under a World Bank-funded Cyclone Rehabilitation Project, and another that was approved but postponed because of the current political climate.

Under the Dreketi project, which was initiated with funds from the Fiji Government and was subsequently supplemented with bilaterial aid from the Australian Government, the plan was to bring about 725 hectares of land under a double-crop irrigated paddy. Of this, an estimated 240 hectares was land under mangroves, 260 hectares was salt-intruded area, and the remaining 225 hectares was preproject riceland.

Reclamation Cost. The Dreketi Scheme was carried out in three phases. The actual costs of Phases I and II are not clear because of poor records, duplication of work and reconstruction, and replacement of a water pumping system run by electric generator-driven pumps with gravity-fed irrigation system (Lal 1989a). The third phase was to have been completed by 1988 but was postponed because of the military coup. This analysis assumes that the project would have been completed by 1988. (See Table 12 for capital costs of "with and without" *tiri* developments.)

Rice Production. The Dreketi Scheme was developed with the objective of decreasing rice imports by increasing local production using irrigated double crops and increasing land under rice. The reclamation of mangrove lands was partly seen as providing the latter without facing land tenure problems (as mangroves are generally considered Crown property). Furthermore, under the scheme, the plan was also to increase land under rice by draining adjacent salt-intruded areas. Reclaimed saline soils were to increase rice lands in the area by more than 200 percent.

What was not considered, however, were the problems involved in bringing saline mangrove soils to full production. As mentioned earlier, once drained, mangrove soils were expected to be in full production within 5 years (or "a minimum of 3 years," Viner n.d.), but production from reclaimed lands was much more complex than anticipated.

Table 12. Capital costs of the Dreketi Project: Phases I to III

	I	I/II	II	III
Year spent	1978	1981	1985	1987
With tiri	1,565,000	140,000	457,000	608,418
Without tiri	1,191,000	53,000	263,000	245,518

Source: See Lal (1989a).

Note: Figures (in 1986 dollars) have been rounded to the nearest thousand.

Rice yield from reclaimed soils. The time taken for full production depends on the type of mangrove soils present. Data on the distribution of soil types (Chandra et al. 1973) and actual farm yield over the past 10 years reveal that only a small area of saltwater-inundated soso soils could become productive within the projected 5 years, whereas farms on dogo soils were still unproductive after 10 years of reclamation. The Colonial Sugar Refining Company also had similar problems with salt leaching and rice and sugarcane production on mangrove reclaimed land at the turn of the century. For example, the 158 hectares of land reclaimed for sugarcane production in 1899 at Vuo in the Northern Division was a failure, at least initially. Despite planting rice to encourage the "sweetening process" (i.e., desalination), the Vuo reclamation project had failed "without producing a grain" even after 8 years of reclamation (Lal 1989a).

Considering the level of acidity and exchangeable electrolytes and the rate of desalination up to now, the Dreketi land would require 15 to 20 years of proper farm management before dogo soils could become productive again (J. Singh, pers. com. 1988). Productivity is delayed despite the use of a locally bred, new salt-tolerant and high-yielding hybrid variety (K127) later named Deepak (Reddy 1987). Deepak, a robust semi-dwarf

Table 13. Five-year average yield for saline and nonsaline soils for Dreketi I: 1978-86

Period	Saline (t/ha)	Nonsaline (t/ha)
1978-82 main season	1.13	2.11
1978-82 off season	1.93	2.60
1983-87 main season	2.63	2.78
1983-86 off season	2.62	2.07

Source: See Lal (1989a).

resistant to lodging, is a hybrid produced by a cross between a local variety (Lalka motka), which is photoperiod sensitive, tall, and well adapted to problem soils, and IR661 from the International Rice Research Institute, which carries semi-dwarf and photoperiod nonsensitive genes (Reddy et al. 1988). It also is photoperiod nonsensitive, which enables it to yield two irrigated crops a year. Because of its salt tolerance and high yields, Deepak is the only rice variety recommended by the Ministry of Primary Industries for the mangrove saline soils.

Koronivia Research Station's trial results with the high-yielding variety, using fertilizers with high phosphorus, produced 3 to 4 tonnes per hectare per season. On average, trial yields of 5.5 tonnes per hectare per year have been produced on saline soils after 5 years of reclamation (Reddy et al. 1987). On the soso soils, which did come under production within the projected 5 years, the average yield was 1.1 tonnes per hectare in the main season and 1.9 tonnes per hectare during the off season, giving an annual yield of 3 tonnes per hectare (Table 13). Thus, soso soils could produce the full potential yields of about 5 tonnes per hectare from double-cropping irrigated rice but only after 5 years of desalination.

Table 14. Projected yield figures derived from actual farm data for 1978-87

Soil type	Yield (t/ha/season)
Better soils	3.5
Nonsaline (non-*narewa*)	2.5
Narewa soils 1-5 years	2.1
Narewa soils >5 years	2.7
Saline *soso* soils 1-5 years	1.5
Saline *soso* soils >5 years	2.6
Dogo soils once under production: usually after 15-20 years	1.5
Dogo soils after 20 years	2.6

Sources: Compiled from Dreketi Irrigation Project Production Data, 1979-87; Reddy (1982); Reddy et al. (1986, 1987).

Dogo soils, however, would require more than 15 years to produce 1.5 tonnes per hectare and more than 20 years to reach the projected full potential (Table 14). It should be remembered that with *dogo* soils, complete flooding and irrigation are essential for production. As discussed earlier, *dogo* soils not only have high levels of electrolytes and aluminum but also high pyrite content, which when exposed to the atmosphere is oxidized to sulfuric acid, producing what is generally called acid sulphate conditions. The acid sulphate soils become almost neutral in pH only when they are fully submerged and are under anaerobic conditions.

Data for the nonsaline farms did not include the better soils where high-yielding varieties were planted in the main season. Generally, on better soils the traditional variety *Uttam* is planted because it brings a higher price. The Ministry of Primary Industries, however, is recommending switching to the high-yielding variety *Deepak.* Average farm yields of nonsaline soils that used *Deepak* was 7.5 tonnes per hectare.

Financial and Economic Price of Rice. Rice production in Fiji is geared toward import substitution. Locally, the average farm gate price for Uttam was $350 per tonne, while Deepak brought only $284 in 1986. The opportunity cost, however, of not producing local rice is the border price of the imported Thai rice. The estimated shadow value of Deepak equivalent rice, with a paddy recovery rate of 66 percent, is $339 per tonne and $407 per tonne for the traditional variety (Lal 1989a).

Cost of Saline and Nonsaline Farms. The net benefits derived from rice farming on reclaimed mangrove soils is a function of the cost of farming and the variety used. On stylized saline and nonsaline farms with recommended farm inputs needed to produce optimum yields, the out-of-pocket expenses for saline soil farmers is about $115 per hectare higher than that for their counterparts on nonsaline soils. But without the subsidy, which is $171 per hectare for saline soils and $104 per hectare for nonsaline soils, the saline soil farmers would have spent $561 and the nonsaline farmers $379 (Lal 1989a). In economic cost, the saline farms cost society $638 per hectare while the nonsaline farms cost only $457 per hectare.

The higher cost of maintaining saline farms is attributable to nutrient deficiencies and chemical toxicities in saline soils, which require greater application of fertilizers, insecticides, and herbicides (Table 15) (Reddy 1987). For example, the recommended rate of phosphate application was 125 and 325 kilograms per hectare for nonsaline and saline soils, respectively. Similarly, 1 kilogram per hectare of orthene was applied on nonsaline soils, whereas 3 kilograms per hectare was used on saline soils (Reddy 1987; Lal 1989a).

Furthermore, reclaimed soils with their characteristic physico-chemical properties require different farm management practices. One of the most important farm practices crucial to mangrove soils productivity is shallow plowing. Considering that potential acid sulphate soils are present 20 to 30 centimeters

Table 15. Mangrove problem soils and chemical-related stress for rice

	Dogo	Soso
Salinity	++	+
Nitrogen deficiency	++	+
Phosphorus deficiency	++	+
Iron deficiency	++	
Aluminum deficiency	++	+
Zinc deficiency	++	+

Sources: Compiled from Chandra et al. (1975); Reddy (1982); Moormann and Pons (1975).

++ = Extreme deficiency or toxicity.
+ = Some deficiency or toxicity.

below the surface, such lands require shallow plowing to prevent the subsurface layer from being exposed to the oxidizing processes, thus causing an increased acid toxicity to rice. This was the major problem in the early days of the scheme.

Because of the overall stress and differential farm inputs required, saline farms are financially and economically more expensive to put to productive use, in addition to giving a much lower expected yield. Reclaimed mangrove land under full production would still be economically less profitable than nonsaline farms because of higher farm costs and lower yields per unit area. Nonsaline but saturated soil farm would yield an economic net benefit of $601 per hectare per season within 1 year of drainage; nonsaline but saturated narewa soil, $642 per hectare after 5 years; and dogo soil, $243 per hectare after perhaps 20 years. But reclaimed soso mangrove soil would produce an economic rent of $243 per hectare per season after only 5 years. The better soils, however, which are put to double cropping, would produce an economic rent of $967 per hectare per season.

Though positive rent is possible from nonsaline and saline soso soils, the dominant dogo soil in the project area gives negative returns for the earlier years of the project, thus affecting the overall economic evaluation of the Dreketi Irrigation Project.

Net Economic Benefit of the Dreketi Project

To evaluate the net economic value of mangrove reclamation per se, a "with and without mangrove reclamation" analysis of the Dreketi Irrigation Project is undertaken for two different scenarios: one where the project includes irrigation as well as mangrove reclamation, and the other where only irrigation of the existing rice lands and waterlogged non-tiri soils is undertaken.

Net present value of the increased rice production from the Dreketi Irrigation Project with tiri reclamation, but excluding the costs incurred for forestry and fisheries resources foregone, was estimated at $3.6 million. At the same discount rate of 5 percent, however, the development scheme without tiri reclamation gave a net benefit of $3.8 million.

Thus, "with and without" analysis of mangrove reclamation produces a marginal net benefit of negative reclamation even without considering the foregone benefits of fisheries ($662,000) and forestry ($51,000) use. Including the minimum value of the mangrove ecosystem, estimated from the foregone benefits of the forestry and fisheries products alone, the development net benefits of the Dreketi Scheme are negative $939,000.

If the effects of ecological characteristics of the mangrove soils, which determine the time taken for freshly reclaimed soils to become productive, were to be incorporated in the benefit-cost analysis, then rice production is not economically viable even when irrigation is used. This is contrary to the generally accepted view that reclaimed mangrove land could be successful in producing a double crop of rice if irrigation were available (e.g., Law Wei Mein 1985; Hardjowigeno 1985; Aksornkoae 1985).

The preceding conclusion emerges even when the foregone benefits of the in situ uses of mangroves are not included in the analysis. As seen earlier, similar negative net benefits of reclamation are also the case where development of mangrove area is undertaken without the availability of irrigation and where the more profitable sugarcane is the intended crop.

SECTION 7

DISCUSSION AND CONCLUSION

The effects of, and the constraints imposed by, the ecological characteristics of the ecosystem are essential variables that need to be explicitly incorporated into an extended benefit-cost analysis. For the agricultural development projects on reclaimed mangrove land in Fiji, if the ecological characteristics were ignored, then the society not only loses a naturally sustainable ecosystem but also incurs financial costs. In both case studies examined, reclamation with or without irrigation for rice and sugarcane/shrimp farming, respectively, the net present values, using a 5 percent social discount rate and a 50-year planning horizon, of the developments were negative (Table 16).

In the reclamation of 350 hectares of mangroves for sugarcane cultivation and the aquaculture project at Raviravi, the opportunity cost of reclaiming was negative $181,000 per year, whereas the annual marginal net benefit of the fisheries and forestry products foregone was $52,000 and $3,000, respectively. This implies that society not only saves on the in situ benefits of the ecosystem by not reclaiming mangrove areas but also makes an economic saving of $181,000 per year.

SENSITIVITY ANALYSIS

Desalination Process

As there is some uncertainty about the rate of desalination process and thus the projected yields from the cane land as well as aquaculture ponds, sensitivity analysis using different scenarios does not affect the conclusion (Table 17). If instead of 30 years for the reclaimed farms to produce 56 tonnes per

Table 16. Marginal net benefits of reclamation without and with irrigation at Raviravi and Dreketi schemes, respectively

	Lump sum NPV	Annual NPV
Agricultural reclamation without irrigation at Raviravi (350 ha): 282 ha under sugarcane and 24 ha under aquaculture ponds		
Development NB	-3,295,000	-181,000
In situ NB foregone		
Fisheries	957,000	52,000
Forestry	57,000	3,000
Total	-4,309,000	-236,000
Agricultural reclamation with irrigation at Dreketi (242 ha)		
Development NB "with and without" *tiri*	-227,000	-12,000
In situ NB foregone		
Fisheries	662,000	36,000
Forestry	51,000	3,000
Total	-939,000	-51,000

Notes:
1. The estimate of the foregone fishery marginal NB assumes a 50% decline in the yield.
2. The Fishery NB for Raviravi = 50% x $5,468/ha x 350 ha; for Dreketi = 50% x $5,468/ha x 242 ha.
3. The Forestry NB foregone for Raviravi = $163.99 x 350 ha; for Dreketi = $208.71/ha x 242 ha.
4. Figures have been rounded to the nearest thousand.
5. Totals do not add up because of rounding.

hectare (as assumed in the previous analysis of the Raviravi project), it is assumed that the cane yields are to reach the project optimum yields of 56 tonnes per hectare within 20 years (Scenario Two) or 15 years (Scenario Three) of the project completion, the net benefits are still negative. Similarly, if

Table 17. Development net benefits of the Raviravi reclamation under different assumed desalination rates

Scenario	Time to reach 56 t/ha cane (yr)	Shrimp yield (t/ha)	Lump sum NPV of NB
One	30	1.8	-3,295,000
Two	20	1.8	-3,078,000
Three	15	1.8	-2,886,000
Four	30	2.5	-2,831,000
Five	30	1.8	-2,822,000
Foregone *in situ* NB (from Table 11)			
Fisheries			957,000
Forestry			57,000

Notes:
1. Scenario One-Four: 282 ha under sugarcane and 67 ha under aquaculture.
2. Scenario Five: 200 ha for sugarcane and 150 ha for aquaculture ponds.
3. Figures have been rounded to the nearest thousand.

the projected higher figure for the shrimp yields of 2.5 tonnes per hectare is to be used (Scenario Four), the net benefits are also negative. The estimated net returns from the Raviravi project are again negative when a larger area of 150 hectares of the total 350 hectares, as currently being proposed, is to be allocted for the relatively more profitable shrimp farming (Scenario Five).

The overall net development benefits decrease further when the estimates of the foregone net benefits from the ecosystem are included, although only a part of the value of the goods and services provided by the ecosystem is included. A similar conclusion is also reached for reclamations involving irrigation, which is interesting because irrigation is believed to accelerate the desalination process and produce viable uses in the marginal

reclaimed mangrove soils (Law Wei Mein 1985; Hardjowigeno 1985; Aksornkoae 1985).

In the Dreketi Rice Scheme, where mangrove land is reclaimed with irrigation, the estimated present value of the net benefit of reclamation, including the foregone in situ benefits, is also negative $939,000 (Table 16). That is, a "with and without" analysis of the net benefits of the Dreketi Scheme gave a negative value of $227,000 with an estimated loss of the in situ benefits of $662,000 from fisheries and $51,000 from forestry products. Thus, the opportunity cost of developing (-$12,000) is far outweighed by the sum of the annual loss of fisheries ($36,000) and forestry ($3,000) harvests (Table 16).

No agricultural development is still the only rational choice, although the estimates of the in situ benefits used represent only minimum values, and there are some uncertainties regarding the actual functional (quantitative) relationship between the mangrove forest area and the fisheries output. The estimates of the in situ net benefits of the mangrove ecosystem represent a minimum value, as only the benefits directly derived from the consumption of the forestry and fisheries products supported by the ecosystem are measured. The NPV of the fisheries benefits under the assumption of a marginal decline of 50 percent is about $2,700, whereas the average forestry NPV for the nation as a whole is about $200. Marginal decline of 50 percent of the fisheries resource, together with the average loss of the forestry resource ($2,900 per hectare), is close to the maximum amount of compensation--about $3,211 for mangrove reclamation in the Ba Delta, where the traditional fishing right (TFR) owners have been the most politically assertive. The off-site fisheries benefit is at least ten times greater than the on-site forestry net benefit (Figure 4). This implies that if only the on-site costs and benefits were included in any project

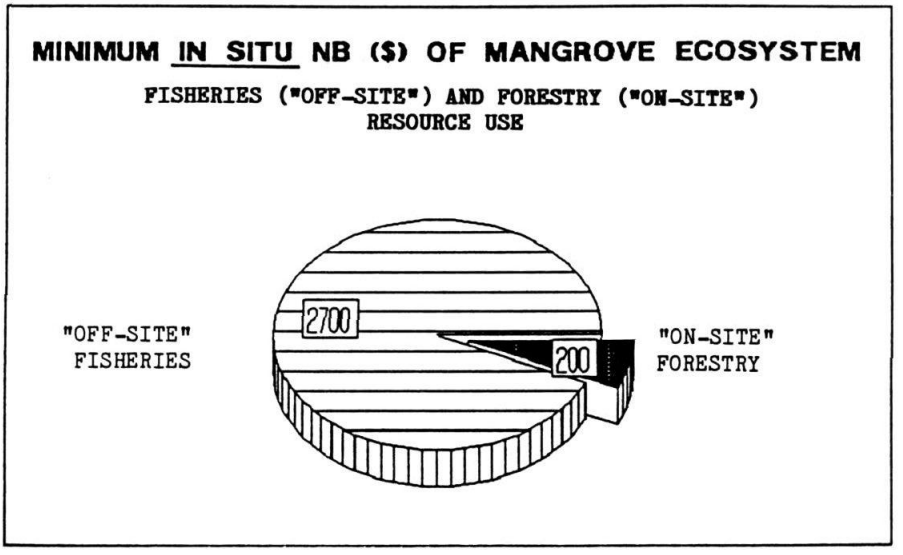

Figure 4. Comparison of net benefits derived from use of "on-site" and "off-site" mangrove resources.

evaluation involving mangrove ecosystem, society may lose a valuable resource.

The preceding estimate of the in situ net benefits of mangrove ecosystem does not include the value of the services provided by the system, such as the mangrove ecosystem's role in soil erosion control, flood mitigation, and filtering of nutrients (as discussed in Section 1). Using the alternative cost approach, rough estimates of the annual net benefit of other environmental uses, such as the nutrient filtering services that the mangrove soils can provide at capacity, give an average benefit of $106,250 per hectare or an annual benefit of $5,820 per hectare. As noted earlier, however, this figure needs to be treated with caution because it represents the average and not

the marginal value, which is the value used in economic benefit-cost analysis. The difference between the two would be significant where large areas of mangroves are present. Further, using the incomes approach, other values, such as the option value in knowing that the mangrove system exists and can be used in the future (Cicchetti and Freeman 1971; Bishop 1982), and the intrinsic values of the ecosystem, are not included. Thus the foregone net benefits from marginal loss of fisheries and forestry products are the minimum estimates of the benefit that a society receives from the natural and dynamic mangrove ecosystem.

Theoretically, the recompense sum given to the "owners of the resource" would have been able to capture all of these tangible and intangible benefits (Cheung 1970). The recompense sum should thus be greater than the estimates derived from using the incomes approach, as was the case in the development of Tokyo Bay (Hanayama and Sano 1981).

As discussed in Section 5, however, the recompense sum paid to traditional fishing right (TFR) owners in Fiji is far below the estimates that were arrived at using the incomes approach. The average recompense sum of about $30 per hectare per year for nonindustrial uses is still far less than the fisheries net benefit estimates alone. The recompensation figures do not compare well with the benefits foregone even under different assumptions about the functional relationships of the dependent fisheries to the mangrove areas. As seen earlier, it is only in situations where the maximum lump sum recompense of $3,211 per hectare of mangrove area reclaimed is paid, as in the politically active Ba Province, that the values approximate the estimates of 50 percent of the marginal loss of the fisheries plus the net benefit derived from the use of the forestry resource, derived from using the incomes approach. In the Ba Province, the same TFR owners were able to obtain $6,250 per hectare for the

reclamation of about 1.1 hectare of foreshore area for wharf development.

One reason the TFR owners did not obtain the full recompense value, as reflected by the preceding estimates using the incomes approach, could be the uncertainty about the definition of the mataqali rights. Historically, the Colonial Government has always regarded mangrove areas "being under Crown Grant, while recognizing certain rights of user of such foreshore in certain instances." However, there has always been a dispute as to what these rights were. As a result, at the turn of this century leases for development were granted treating mangrove areas as Crown land in some instances and as Native land in a few cases.

Today, as discussed in Section 2, the government has, on the one hand, ruled that the "Fijian customary rights are not compensable rights," while, on the other hand (under the same Cabinet decision), instituted an arbitration process to determine compensation for any losses incurred by the TFR owners from reclamation or any development activity within the coastal waters. The dispute over the ownership rights of the coastal waters and the resources therein still continues (Council of Chiefs 1979). Given this uncertainty, the TFR owners were not in a strong position to negotiate and obtain the true "willingness to pay" from the developers or the minimum "willingness-to-accept compensation" reflecting the marginal losses incurred.

The decision not to develop is still the optimal choice even where these off-site benefits of the dynamic and naturally viable system were assumed to be zero. It costs society more to use the reclaimed land than the benefits it can expect to obtain in return, and it loses a naturally viable resource which, if nothing else, may have an option value to society.

Thus, reclamation for agricultural purposes cannot be justified in these circumstances. However, this conclusion also depends on what social discount rate and planning horizon are used; here 5 percent and a 50-year planning period are used.

Effect of Discount Rate and Planning Horizon

There is uncertainty about what social discount rate should be used for future costs and benefits (Marglin 1963; Lind et al. 1982; Ray 1984). On the one hand, it has been suggested that low social discount rates should be used where long-term damages of the projects are greater (Fisher and Krutilla 1975). On the other hand, low discount rates may lead to higher investments and create greater damage to environments (Fisher and Krutilla 1975). It has been suggested that social discount rates of 1 to 6 percent be used for projects with long-term environmental effects (Lind et al. 1982).

Varying the social discount rate and using a 50-year planning horizon for the computation of the present net benefit of the agricultural projects does not change the conclusion of no development. Reclamation without irrigation is still negative at a zero discount rate (i.e., when the future is not discounted--a position usually taken by ecologists) and even when the in situ benefits are ignored (Table 18).

On the other hand, in the case of reclamation with irrigation at Dreketi, using "with and without" analysis and including the foregone in situ benefits, the NPV is only marginally positive at a zero discount rate. Since the estimates of the foregone in situ benefits are considered only a minimum value of the ecosystem, the mangrove reclamation for agricultural purposes cannot be justified using the preceding criteria and a 50-year planning horizon.

To justify reclaimed mangrove land for agricultural uses, according to the preceding criteria, the NPV of the development benefits will have to be at least greater than the minimum net benefits of forestry, $200 per hectare, plus the fisheries, $2,700 per hectare. That is, given the prevalent market prices and the projected yields from the agricultural uses, the net benefits for the Raviravi project will have to be increased by at least about $670 per hectare per year, whereas for the Dreketi project, it will have to increase by $210 per hectare per year.

Table 18. Effects of social discount rates and planning horizon on development net benefits

Discount rate (%)	Dreketi		Raviravi	
	50 yrs	100 yrs	50 yrs	100 yrs
10	-905,000	-900,000	-2,836,000	-2,835,000
5	-939,000	-832,000	-4,310,000	-4,297,000
3	-789,000	-394,000	-5,277,000	-5,228,000
1	-337,000	127,000	-6,614,000	-6,417,000
0	112,000	3,495,000	-7,474,000	-7,037,000

Note: Figures have been rounded to the nearest thousand.

Given the ecological conditions present, the chances of such increases are nil.

On the other hand, if the planning horizon were increased to 100 years and low discount rates, such as 1 percent or zero percent, were used, rice farming on reclaimed mangrove soils at Dreketi rates would yield positive net returns ($1.2 million at 1 percent and $3.5 million at zero discounting) under the assumption that no further capital investments are made and constant prices prevail. But at higher discount rates of 3 to 10 percent (10 percent was used by the government), even a 100-year planning horizon could not justify mangrove reclamation for rice as well as sugarcane farming. Sugarcane farming, a crop less tolerant of saline and acidic conditions than rice, could not be justified even when the future is not discounted and a longer planning horizon is adopted.

There are many reasons, besides the high initial capital costs needed to clear mangrove lands and to construct and maintain seawalls, bunds, and dykes, for the nonviability of agricultural projects on reclaimed mangrove areas. Even where the initial capital costs of reclamation are treated as sunk costs (e.g., in the Raviravi Project), the net development benefits are still negative (Lal 1989a). But the most important

reason for the negative development benefits is the inherent characteristics of the mangrove soils. Given their physico-chemical characteristics, the reclaimed saline soils become productive only after a long period of desalination. The inherent toxic concentration of aluminum and iron is the main inhibiting factor, along with a low pH for the plant growth. These factors, together with the low phosphate retention in the mangrove soils, prolong the desalination process, which makes the soils difficult to use (Moormann and Pons 1975). The reclaimed saline soils require more fertilizer and other chemicals and different farm management practices, all of which make them more expensive to cultivate. In addition, they have lower yields because of the stresses caused by these biochemical factors which are not present in the nonsaline soils. Furthermore, because the burrowing activities of the mud lobster (T. anomala) cause leaks, the desalination process is often reversed.

Similar failures of mangrove conversion for agricultural purposes have been recorded in other tropical countries. For example, in West Africa, frequent failures in rice production on reclaimed mangrove soils have been caused by drought conditions (Moormann and Pons 1975). Problems in fluctuating yields due to desalination and regeneration of the acid sulphate conditions have also been reported from Vietnam and Sierra Leone (FAO 1982). The reversal of the desalination process and the annual regeneration of acid sulphate conditions result from droughts, and surface to the top layers with subsequent rains (Coulter 1973; Moormann and Pons 1975). Even where initial yields are relatively high, such as in the Sunderbans, India, the reclaimed areas, because of salt intrusion and acid sulphate conditions, are not fully used (Bandopadhyay 1985) or have to be abandoned, as in the Chittagong coastal plains (Amirul Islam 1964) and in Sarawak (Moormann and Pons 1975). Where these acid sulphate soils are farmed, careful farm management practices, such as shallow plowing, are needed to prevent exposure to the atmosphere of the potential acid sulphate subsurface soils (Moormann and

Pons 1975). Furthermore, extreme care is needed so that the seawalls and bunds do not develop a leak, which would allow the intrusion of saline water to cause reversal of the desalination process, and to prevent the capillary rise of subsoil salinity during dry seasons (Moormann and Pons 1975). The risk of these occurrences is very high.

The question that arises is, "Why has the government undertaken reclamation of mangroves for agricultural purposes?" To understand this question, one would need to examine the politics of the country. This complex subject would require a separate study of its own, though aspects of this have been alluded to in this study. Briefly, the heart of the matter lies in the competition for resources between the two major ethnic groups, Fijians and Indians. To take an example relevant to this study, the indigenous Fijians have inalienable rights to 83 percent of the land in Fiji, but the Indians, who are the main agriculturalists, can only lease land for limited periods. This situation creates insecurity and political alienation among the farmers. The government, dominated by representatives of the land-owning Fijians, has generally taken only a short term and politically expedient view of the situation and has reclaimed land to appear to be doing something for the "landless people," the Indians. Furthermore, a government is not a single decision-maker, as assumed in this model. Some government agencies generally supported further reclamations to "justify their own existence" with the hope that more land would eventually be available for productive use.

Political expediency and short-term self-interest are a fairly universal problem and one not peculiar to Fiji (Buchanan and Tullock 1964). For example, in Britain too, short-term interests of government agencies led to drainage and reclamation of wetlands for agricultural purposes (Nash and Bowers 1988).

CONCLUSION

In conclusion, this study, using Fiji as a case study, demonstrates that before any development of natural systems is undertaken, one has to take a holistic approach in project evaluation. It shows that for a rational use of natural resources, an ecosystems approach that incorporates the interactions of the ecological, economic, and institutional factors and processes has to be adopted in the benefit-cost (BC) analysis framework.

Specifically, the study uses an ecosystem as the boundary and treats the in situ benefits as an integral part of a project for its evaluation, using the extended BC model. In estimating the in situ benefits of a mangrove ecosystem by the incomes approach, it was found that subsistence net benefits of using the fisheries products are almost equal to that of the commercial users. In the case of forestry product use, the net benefits for subsistence were greater than those for commercial. This emphasizes the need to ensure that in developing countries where subsistence economy is important, the value of nonmarket-based subsistence uses should be included in project evaluation.

Further, using two ongoing agricultural projects on reclaimed mangrove lands in Fiji, it was demonstrated that, where mangrove reclamation is carried out for agricultural purposes, developments are not economically viable if one takes into account the biological and economic characteristics of the ecosystem. Most important, the study shows that unless the ecological constraints of an ecosystem are incorporated into a benefit-cost framework, the society loses a naturally viable ecosystem without receiving positive returns from their alternative uses.

Considering that the application of the economic model and the no-development decision depend on various assumptions made during the analysis, sensitivity analysis relaxing some of these assumptions was carried out. Relaxing the assumptions made no

difference to the conclusions. Decreasing the time required for the desalination of the soils and for the land to produce optimal yield of sugarcane still gave negative net benefits. Similar negative results were also obtained when the shrimp yield in the aquaculture ponds were assumed to be 40 percent greater, as proposed by the France Aquaculture. Increasing the land area allocated to the more profitable shrimp culture, at optimum yields, to 150 hectares with a corresponding decrease in the sugarcane farming to 200 hectares still gave negative net benefits.

Furthermore, no development for sugarcane farming is still the conclusion, although only minimal estimates of the in situ benefits were used. The conclusion does not change even when the in situ net benefits of the mangroves were not included in the analysis.

The conclusion is similar where reclamation is carried out with irrigation and double cropping of rice using the high-yielding variety Deepak. The net benefit of reclamation with irrigation is still negative even under the assumption of zero in situ benefits derived from the fisheries and forestry products.

Reclamation for agricultural purposes cannot be justified even if future benefits and costs were given equal weight as the present ones, or conversely if the future were to be discounted at discount rates ranging from 10 to 0 percent and using a 50-year planning horizon (Table 18). On the other hand, with a planning horizon increased to 100 years, only rice, which generally is a more salt-tolerant crop, gives a positive net return and that too at very low, 0 to 1 percent, discount rates (Table 18). However, the analysis assumes that there is no leakage in the sluice gates, the bund walls are maintained, and shallow plowing and proper farm management practices are followed. In other words, the desalinated conditions are maintained and acid sulphate conditions are prevented from developing. It also assumes that no further capital investments

are needed. But the chances, as experienced, of maintaining ideal conditions are nil, and agricultural projects on reclaimed mangrove soils are not economically viable.

This study demonstrates that where the biological and the inherent physico-chemical characteristics of an ecosystem that affect the development net benefits are incorporated into the BC analysis framework, agricultural projects on the reclaimed lands cannot be justified. However, a reclamation project may be justified if the development is site-specific and the area has specific locational advantages or if there are institutional constraints, as in the residential/industrial development in Fiji (Lal 1989a). In such a situation, where the net benefit stream is independent of the ecological characteristics of a system, or where despite taking the ecological characteristics into account, no definitive choice can be made, other criteria may need to be adopted if conservation is desired.

Further, this decision criterion, which is based on current profitability and not on future demand, technology, and so on, is optimal only because of reversibility and the assumption of instantaneous adjustment (Arrow 1964). Krutilla and Fisher (1985) show that if prices and costs were not constant and decisions were irreversible, then the optimum level of investment would be lower than what is warranted by current benefits and costs.

Alternative Framework

Given all the uncertainties and assumptions underlying the methodologies used, an analyst is faced with the intractable problem even where extended BC analysis is used adopting different valuation techniques. It is still possible to cause the irreversible commitment of the mangrove ecosystem even if all the benefits and costs were known and BC analysis were to be properly used.

The extended BC analysis framework, despite its usefulness in systematically identifying and estimating the benefits and costs

of a development project, is also limited to some extent because of the need for monetary valuation of the in situ benefits of an ecosystem. Some of the direct and indirect uses of an ecosystem and the ecological values, as discussed earlier, may not be known or are difficult to measure.

The BC analysis is based on comparison of marginal effects, the actual values of which may not be known or known with a great degree of uncertainty. Where there is uncertainty, a minimax approach adapted from game theory had been suggested (Shabman and Bertelson 1979). The minimax strategy suggests selecting a course of action that minimizes the maximum loss to the present and future generations. This strategy could also provide an economic justification for "preservation."

Furthermore, because of synergistic and cumulative effects of developments, extinction of some habitats or species may still possibly result. For an economic analysis that considers the cumulative effects of individual developments (e.g., the uncertainties regarding technological changes, changes in prices), a paradigm shift in resource economics is needed (Turner 1988). Such a shift would need to incorporate the interaction between the ecological, social, and economic factors.

This could be used to define the macro-environmental standards; the safe minimum standards of Ciriacy-Wantrup (1952) and Bishop (1978). These standards in turn define the overall constraints within which resource allocation and management of human activities are undertaken. Within such a revised theoretical structure, the expanded BC framework would still be a valuable tool but only at a second-tier level (Figure 5) (Lal 1990).

Such a macro-environmental standards approach (MESA) that relied on "districting" (i.e., ecosystem "zoning") of mangrove wetland has recently been attempted on a small island state of Kosrae in the Federated States of Micronesia (Lal 1989b). But its effectiveness is too early to predict as the Kosrae Coastal Zone Management, of which the Wetland Resource Utilization and

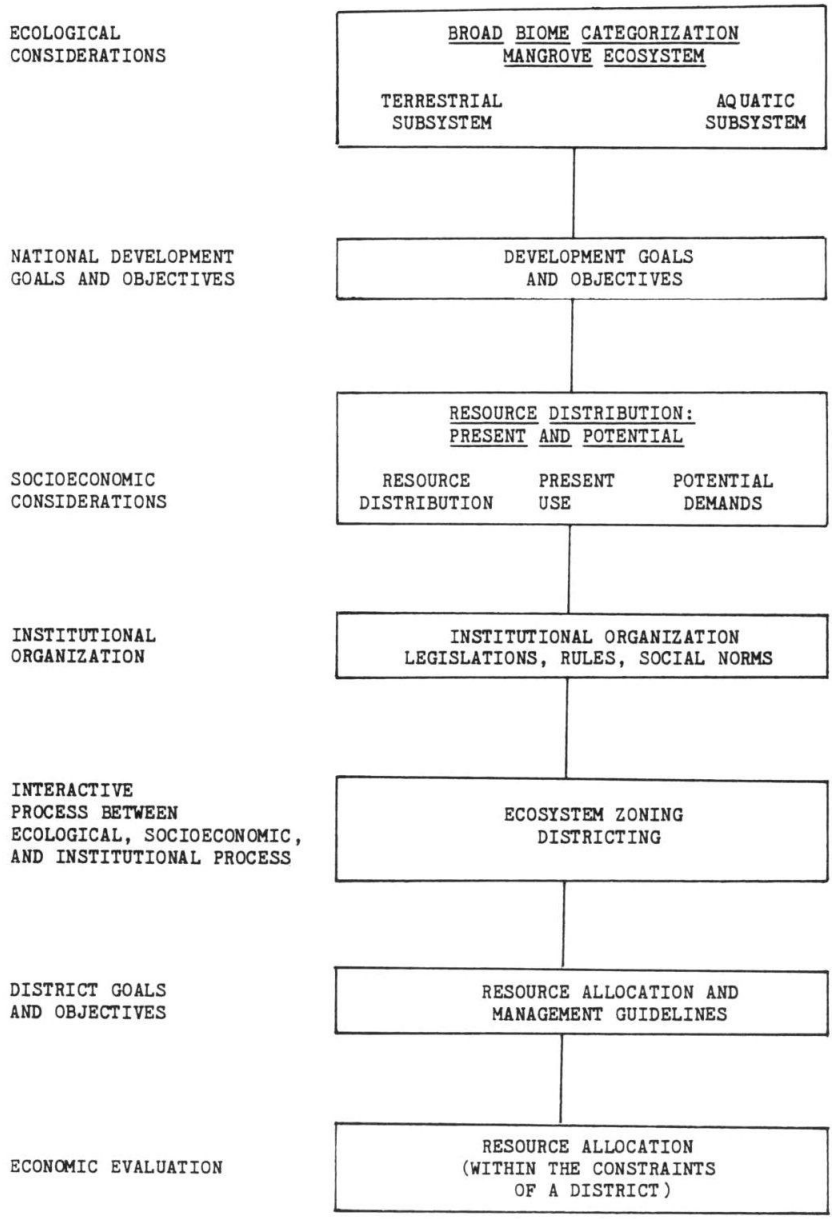

Figure 5. An integrated approach to wetland resource allocation and management.

Management was a component, is just being implemented, and BC analysis of projects within the districts has not been undertaken.

The approach taken in this study has wide applications beyond mangrove conservation in Fiji. The study has demonstrated that before any development project involving fragile natural ecosystems is undertaken by the private or public sector, a detailed project evaluation is essential. It emphasizes the value and the necessity of adopting a multidisciplinary approach in evaluating an ecologically complex natural resource. The study also highlights the limitations of using only BC analysis framework for the evaluation of projects involving complex ecosystems. The evaluation techniques adopted depend not only on the ecological characteristics of an ecosystem but also on the institutional characteristics governing human activities.

Reiterating the point made at the outset of this study, we conclude that for a rational use of natural resources, one has to take an approach that incorporates the interactions of the economic, ecological, and institutional factors, as it is the totality of these that determines the outcome of any activity within an ecosystem.

APPENDIX

ECOLOGICAL ECONOMIC MODEL FOR MANGROVE WETLANDS

The optimal control theory and the benefit-cost analytical framework are used to develop a theoretical model in which both "on-site" and "off-site" benefits and costs of development are included. The mangrove ecosystem, with its dependent forestry and fisheries resources, is treated as a capital resource, valued for its growth in stock, the flow of harvests, and its ecological benefits. The development benefits and costs are also treated as a function of ecological characteristics.

The model assumes a single omnipresent manager whose objective is to maximize net social return from his mangrove ecosystem. This implies that project boundary is defined as determined by ecological processes, which allow the "off-site" and temporal benefits and costs to be treated as an integral component of the project evaluation instead of as "externalities." Under perfect conditions, this would give an optimal strategy for the use of interdependent and often conflicting capital and resource stocks, and flows can be determined endogenously (Krutilla and Fisher 1985) and for each time period (Clark 1976).

ECOLOGICAL AND ECONOMIC BENEFITS OF IN SITU USES OF MANGROVES

The mangrove ecosystem is an ecologically complex system and is comprised of terrestrial and aquatic subsystems, with the movement of water providing the linkage between the two. The economic value of mangroves is derived from the recognition that they are a naturally growing resource, which provides a flow of goods and services considered valuable to people. Besides the ecological benefits, other benefits derived from the system can be categorized into direct consumptive and non-consumptive uses. Consumptive uses of products such as forests, fisheries or game animals result from actual harvest of resources that the system supports, whereas indirect uses such as shore erosion protection, flood mitigation benefits, and recreational benefits are based on the maintenance of ecosystems.

Forestry Benefits

A mangrove ecosystem supports a number of plant species that provide important forestry products. Thus, Bruguiera gymnorhriza, for example, is used for timber and firewood and for charcoal production in Fiji. Mangroves were also used for the production of tannin in the first half of the century, though the practice has been discontinued. In Asian countries, however, species belonging to the genera of Avicennia, Rhizophora, Bruguiera and others are still used for tannin production (Hamilton and Snedaker 1984 and UNDP/UNESCO 1987).

The social benefits of forestry products are measured by harvestable timber volume, the social value of the product being the market price under competitive conditions. The social value depends on the forest stock as well as the growth of timber. Thus, the social benefit derived from a mangrove forest is a function of a market-determined price, which in itself is a function of demand, volume harvested, growth rate, and the area of harvestable forest and management strategies (Clark 1976; Samuelson 1976; Berck 1979).

Assume a stylized managed non-virgin forest with single species in which all the trees are of the same initial age and are evenly distributed. Total volume of timber $F_t = A_t * V_t$, where V_t is the stump volume per unit area (Table A.1). Trees grow at the rate of $dF/dt = G^F(F) = A_t\, dV_t/dt$; $dG^F(F)/dt \geq 0$; $dG_2^F(F)/dt^2 \leq 0$. Let f_t be the annual harvest rate. Therefore, growth rate of the forest now is $dF/dt = G^F(F) - f_t$. Let P^F be the price of per unit volume of stump; C^f be per unit harvest and thinning cost, which is a function of the total mangrove area, A(t).

A.1 Symbols used in the ecological economics model

A_o	=	total amount of mangrove land present
S_t	=	area of reclaimed land = $\Sigma^t_{j=0} I_t$
A_t	=	$A_o - S_t$; the area of land under mangrove forest
F_t	=	$A_t.V_t$; V_t = stump volume per unit area of mangroves
X_t	=	amount of fisheries stock present at time t
Z_t	=	physico-chemical characteristics of an ecosystem at time t
Z^d	=	vector of physico-chemical characteristics that affect development costs and benefits
Z^x	=	vector of physico-chemical characteristics that affect fisheries production

Initial conditions of the three resource stocks are:

F(t=0)	=	F_0;	$0 \leq f_t \leq F_t$;
S(t=0)	=	0;	$I_t \leq I_{max}$
X(t=0)	=	X_0;	$0 \leq h_t \leq h_{max}$

The control variables are

I_t	=	investment rate
f_t	=	forest harvest and replanting rate
h_t	=	harvest rate of mangrove-dependent fish per unit boat-net-men effort

The constraints are

dS/dt	=	"growth" rate of reclaimed land
dF/dt	=	$A_t\ dV_t/dt - f_t$; the net growth of forestry resource which is a function of intrinsic growth of timber volume and harvest rate
dX/dt	=	$G^x\ [X_t\ (F_t)] - h_t$; the net growth of fisheries stock

P^d	=	price of unit reclaimed land
C^d	=	present value of a cost of a unit area of reclamation
C^f	=	unit cost of forest timber harvest and thinning
C^x	=	cost of unit harvest of fish dependent upon mangroves
P^f	=	unit timber stump price
P^x	=	unit price of fisheries product

B^d_t	=	$[P^d - C^d(S_t)]\ I_t$; net development benefits at time t;
B^F_t	=	$[P^f - C^f(F_t)]\ f_t$; net benefits of forestry harvest at time t;
B^X_t	=	$[P^x - C^x(X_t)]\ h_t$; net benefits from fish harvest at time t;
B^E_t	=	$B^E(F_t, A_t)$; net benefits of environmental services

λ is the respective shadow value of the growth in capital stock.

δ is the social discount rate

Therefore, the total benefit, B^F_t, is derived from mangrove forest resources in each period, $(P^F - C(F))\ f_t$. That is,

$$B^F = B^F\ (P^F, F, f_t\ )$$

subject to: $dF/dt = G^F(F) - f_t$

Environmental Benefits

Environmental benefits of the mangrove ecosystem include those that are derived from its non-consumptive uses such as bird watching, wildlife photography and other recreational benefits assumed to be a function of the total mangrove area and forest volume. Other benefits such as shore erosion protection, nutrient filtering properties of mangroves, and the existence or option value are assumed to be captured in this function. Environmental benefits are a function of the area under forest and the volume of forestry biomass.

B^E = net environmental benefits in each period

$B_t^E = B_t^E\ (F_t, A_t)$

Fisheries benefits

The stream of fisheries net benefits is a function of the fisheries stock (X_t), harvest rate, h_t and price, P^x and cost, $C^x(X)$ (Clark and Munro 1975). Furthermore, the fisheries stock X_t is a function of the amount of mangrove forest present F_t. Although it is generally accepted that mangroves are important to coastal fisheries, the exact functional relationship between them is not known (Saenger et al. 1983; Hamilton and Snedaker 1984; Hutchings and Saenger 1987; UNDP/UNESCO 1987).

The manner in which the secondary and tertiary productivity (i.e., harvestable fish and nonfish resources) is affected by the presence of mangrove flora depends not only on the detrital inputs but also on the complex biological and chemical processes within the system. Mangrove areas act as a habitat as well as spawning and nursery grounds for fish and non-fish fauna (Odum and Heald 1972; Lal et al. 1984;

Robertson 1988). Not all species caught in mangrove waters are permanent residents. Some species, such as those belonging to the families of Gerridae, Sparidae, Engraulidae and Pomadasyidae, are demersal coastal species but spawn in estuaries (Johannes 1978). On the other hand, some Lethrinus sp., Siganus sp, and Lutjanus sp. inhabit mangroves and migrate to coastal reef slopes to spawn (Johannes 1980). Mangroves provide a habitat for greater refuge for smaller fishes (Robertson 1988).

Mangroves also provide detrital nutrient input into coastal waters that support the coastal fauna (Odum and Heald 1972; Sasekumar and Loi 1983). Moreover, mangroves are an important source of energy and nutrient flow into coastal water (Boto 1982; Bunt 1982). The total amount of leaf litter, bark, and flowers that comprise the mangrove detritus is found to be only marginally lower than the volume of the standing crop (Bunt 1987). In the tropics, detrital production of about 1,000 gm/m^2 or about 1 t/ha/yr (e.g., in Australia, Bunt 1982; and Fiji, Lal 1989a) to 16 t/ha (e.g., in Malaysia, Sasekumar and Loi 1983) has been reported. The variation in detrital productivity is a function of mangrove plant species as well as environmental factors (Duke et al. 1981). In an estuarine-lagoon system, the ratio of potential maximum sustainable fish yields to primary productivity by weight ranged between 0.0008 to 0.01; the latter figure included intensive aquaculture farming (Marten and Polovina 1982). Using Marten and Polovina's ratio and considering the amount of detrital input into estuarine waters from mangroves (1 t/ha), the potential fish yield directly attributable to mangroves could be in the range of 800 kg/ha to 10,000 kg/ha/yr, depending on the productivity of the coastal waters, technology and effort.

The final fate of the detritus depends on the particular food chain it happens to have followed, which, in turn, depends on whether the detritus gets exported into the coastal waters or is trapped within the mangrove substrate (e.g., Robertson 1986; Ong and Sasekumar 1984). The extent of detrital export is a function of the nature of

the wetland soil, types of fauna present in the soils, the degree of ebb and flow tidal fluctuations, and the volume of water flow (Montague et al. 1987; Camocho and Bagarinao 1987).

Initial breakdown of leaves occurs on the surface of the sediment or in the water from which the soluble compounds are leached out (Harrison and Mann 1975; Rice and Tenore 1981). Epiphytic growth of fungi and bacterial populations aids in this breakdown and in the export of nutrients out into the aquatic system (Odum and Heald 1972). Mechanical breakdown of detritus by amphipods, isopods, and other infauna further assists in the release of nutrients trapped in the detritus, thus enabling it to become part of the larger food chain in the aquatic system (Goulter and Allaway 1979; Robertson and Mann 1980).

Detritus may be directly ingested by herbivorous or omnivorous species of fish and nonfish fauna and thus contribute directly to the secondary productivity of the coastal waters. In Australia (Robertson 1986) and Malaysia (Macintosh 1984), for example, crabs, which directly consume leaf litter, are important prey for juvenile fish, which themselves become a part of different food chains. In some cases, the nutrition in the consumed detritus is derived from the community of microbes growing on them (Odum 1970; Ong and Sasekumar 1984). Other food chain linkages were also found. In Malaysia, for example, the mangrove detritus-based bacterial population supported the zooplankton and copepods, which in turn become part of the food chain for benthic and pelagic fishes (Ong and Sasekumar 1984).

Thus, the exact functional relationship between mangrove and fish fauna is complex. Nevertheless, the major primary producers in all these linkages are mangrove plants, which form the basic energy source for the land-water-interface ecosystem. What effect the reclamation of mangroves would have on the secondary and tertiary productivity is not well understood.

IMPACT OF RECLAMATION

Reclamation of mangroves for alternative uses involves foregoing the forest and fisheries products as well as other services that they provide. Though the ecological production relationship within a mangrove ecosystem is obviously complex and the exact functional relationship is not fully understood, reclamation has caused a reduction in organic matter production and fisheries output from mangrove systems. Organic matter production and their calorific values have been found to be significantly lower in disturbed mangrove areas than in undisturbed mangroves. Species diversity of both flora and fauna is also lower in the disturbed areas (Camacho and Bagarinao 1987). In Indonesia, for example, the reclamation of mangrove areas, which serve as nursery grounds for the commercially important penaeid shrimps (Penaeid monodon, P. merguiensis), resulted in the decline of offshore shrimp production (Naamin 1987). The destruction of mangrove areas was also held responsible for the decline of the mangrove crab, Scylla serrata, by about 50 percent (Naamin 1987). Similar reductions in productivity in coastal fauna have also been reported from sub-tropical wetland areas in North America (e.g., Woodburn 1961; Mock 1967; Trent et al. 1973; Boesch and Turner 1984; Turner and Boesch 1988). Positive correlations between penaeid shrimp stock sizes as reflected in annual harvests and coastal wetland areas have also been reported in a number of other cases (e.g., in Australia, Staples et al. 1985; Philippines, Pauly and Ingles 1986; Malaysia, Jothy 1984).

Fish harvests are also greater in mangrove-lined estuaries than in estuaries without mangroves. In Pichavaram, India, for example, fish yields were significantly higher, 260 kg/ha/yr, from an estuary that had mangroves when compared to 120 kg/ha/yr from an adjacent estuary without mangroves (Krishnamurthy and Jeyaseelan 1984). On the other hand, reforestation of mangrove in some areas, such as in

Indonesia, has led to an increase in shrimp production by about 60 percent (Naamin 1987).

Thus, we make a simplifying assumption that all biological and non-biological characteristics (Z^x) of an ecosystem would ultimately affect the carrying capacity, K^o, of the fish and nonfish fauna of the system, given a level of primary productivity. Normally, in bioeconomic fisheries models, the carrying capacity of a system is treated as being constant. Here K^0 is treated as being dependent upon F, the volume of mangrove forest that determines the amount of detrital input and the habitat area. Thus, $K^0 = K(F, Z^x)$ where K^0 is the carrying capacity of the system, Z^x is the site specific characteristics, and F is the forest volume. $dK/dF > 0$, but it increases at a decreasing rate $- d_2K/d^2F < 0$. With each K, the fish biomass at time t, $X_t(\lim t \rightarrow \infty)$ equals K. Therefore, if $K' > K^0$, say, because of increase in coastal mangrove habitat, then $dX/dK > 0$. Since X_t is a function of K^0, and K is a function of F, therefore, $dX/dF > 0$ and $X = X [K (F)]$. The natural growth of fish stock is dX/dt, $dX/dt = G^x (X_t, F_t)$. In the presence of fish harvest rate h_t, the growth function becomes:

$$dX/dt = G^x [X_t (F_t)] - h_t.$$

Let P^x = exogenous price of fish, $C^x(X)$ = unit cost of harvest, which is a function of fish biomass, and h_t = harvest rate at time t. Let the net benefits derived from mangrove-based coastal fisheries in each period be B_t^x

$$B^x_t = [P^x_t - C^x (X(F_t))] h_t.$$

That is, $B^x = B^x [X_t(F_t), h_t]$ is the benefit function for the harvest of fisheries products.

DEVELOPMENT BENEFITS

Let B^d equal net development benefits derived from the reclamation of the mangrove wetland. The net benefits, or economic rent, derived from alternative use of the land is a function of supply of land and its demand for the specific use. It is also

a function of the physico-chemical characteristics of the reclaimed land. The net benefit of reclamation $B^d_t = [P^d_t - C^d_t(S)]\ I_t$, given a particular vector of the physico-chemical characteristics of the land, Z^d_t. P^d is the market value of unit reclaimed land, and it reflects the present value of the income stream obtainable from the reclaimed land. The income stream is itself a function of the physico-chemical characteristics of the land, Z^d. For example, the net benefit stream from rice and sugarcane farming on reclaimed mangrove land is a function of the desalination process, the level of mud lobster activity, and the acid sulphate condition as determined by the soil chemistry and aerobic/anaerobic conditions. That is, $P^d_t = P^d_t(\ Z^d)$. $C^d_t(S)$ is the present value of unit cost of reclamation and subdivision of mangrove land, and it is a decreasing function of the amount of reclaimed land. This is a function of initial capital cost and the annual maintenance cost. I_t is the amount of land reclaimed at time t.

$B^d_t = B^d\ (S_t, I_t, Z^d_t)$.

ECONOMIC MODEL

Assumptions:

1. Prices and costs are constant over time.

2. Objective Function: sole owner's objective is to maximize present value of his net economic benefit streams by controlling the control variables (i.e., the amount of reclamation, forestry, and fisheries harvest rates) (see Table A.1 for notation).

That is,

$$\max_{I,f,h} \int_0^T \{B^d_{t(}S_t,Z^d) + B^F_{(}F_t,f_t) + B^X_{(}X_{t(}F_t),h_t) + B^E_{(}F_t)\}\ e^{-rt}\ dt$$

subject to the constraints,

$$dF/dt = G^F_{(}F_t) - f_t$$
$$dX/dt = G^X_{(}X_{t(}F_t) - h_t$$
$$dS/dt = I_t$$

the initial conditions,

$$F(t=0) = F_o;\ 0 \leq f_t \leq f_{max}$$
$$S(t=0) = S_o;\ l_t \leq l_{max}$$
$$X(t=0) = X_o;\ 0 \leq h_t \leq h_{max}$$

and the terminal values,

$$F(T) = F_T$$
$$S(T) = S_T$$
$$X(T) = X_T$$

Expressing this as a Hamiltonian, H,

$$e^{-\delta t}\,[B^d_t(S_t, Z^d) + B^E(F_t, A_t) + B^F(F_t, f_t) + B^X(X_t(F_t), h_t) + \lambda_1 l + \lambda_2(G(F_t - f_t) + \lambda_3(G(X_t(F_t)) - h_t)$$

where λ is the respective shadow value of the growth in capital stock.

By Pontryagin's conditions of optimality and further rearrangement the following equation is obtained under the assumption of optimal conditions, ($G^X(X^*) = h^*$ and $G^F(F^*) = f^*$), :

$$\delta(P^d - C(S_t)\, e^{-\delta t} = e^{-\delta t}\,[\,\partial B^F/\partial S + \partial B^X/\partial S + \partial B^E/\partial S]$$
$$+ (P^F - C^F(F))\, e^{-\delta t}[\partial(G^F(F) - f)/\partial S] + (P^X - C^X(X))\, e^{-\delta t}[\partial(G^X(X) - h)/\partial S]$$

and under the assumption that in the region of optimal conditions, the cost of harvest does not change (i.e., $\partial C^F/\partial S = 0$, and $\partial C^X/\partial S = 0$), but only the harvest level changes, the preceding equation becomes

$$\delta(P^d - C(S) = [P^F - C^F(F)]\,\partial f^*/\partial S + [P^X - C^X(F)]\,\partial h^*/\partial S + \partial B^E/\partial S$$

Where:

$\delta(P^d - C(S))$ is the opportunity cost of not developing today;

$[P^F - C^F(F)]\,\partial f^*/\partial S$ is the marginal net benefit from the foregone forestry resources if developed today;

$[P^X - C^X(F)]\,\partial h^*/\partial S$ is the marginal net benefit from the foregone fisheries harvest if mangroves were to be reclaimed today;

$\partial B^E/\partial S$ is the environmental services and other values such as the option value and existence values forgone if the mangroves were reclaimed today.

Under the assumption of reversibility and conditions of linearity, constant prices and optimal levels of reclamation, and fisheries and forestry harvests can be determined

endogenously, an optimal steady-state equilibrium solution exists for the control variables (Clark 1976). Let these be equal to I^*, h^*, f^* for the investment rate, fisheries harvest rate, and forestry harvest rate, respectively.

The preceding condition states that if the opportunity cost of not reclaiming mangroves today, which equals social interest rate times net marginal benefit of development ($\delta(P^d - C(S))$, is greater than marginal benefits foregone in the form of fisheries ($\partial B^X/\partial S + (P^X - C^F(X))\, \partial G(X)/\partial S$), forestry ($\partial B^F/\partial S + (P^F - C^F(F))\partial G(F)/\partial S$)), and the environmental services ($\partial B^E/\partial S$), then the manager could reclaim the mangroves. That is, the investment rate, I, is greater than zero. Moreover, if development were the optimal solution, then for each unit of reclamation, the developers should compensate the losers by an amount equal to the marginal value of all the goods and services foregone. This is the weaker Pareto efficient criteria (Mishan 1976).

Conversely, if the marginal benefits of the <u>in situ</u> uses foregone are greater than the marginal benefits of development, then mangroves should not be reclaimed (i.e., $I = 0$). Alternatively, the stock of the mangrove system should be allowed to grow (i.e., $I < 0$), with the result that reforestation is the policy.

This decision criterion, which is based upon current profitability and not on future demand, technology, and so on, is optimal only because of reversibility and the assumption of instantaneous adjustment (Arrow 1964). Krutilla and Fisher (1985) show that if prices and costs were not constant and decisions were irreversible, then the optimum level of investment would be lower than what is warranted by current benefits and costs.

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